# COMBAT RATION ADVANCED MANUFACTURING TECHNOLOGY DEMONSTRATION (CRAMTD)

## "Long Life Ration Packet"

**Short Term Project (STP) #9**

**FINAL TECHNICAL REPORT**
**Results and Accomplishments (January 1992 through November 1992)**
**Report No. CRAMTD STP #9 - FTR 9.0**
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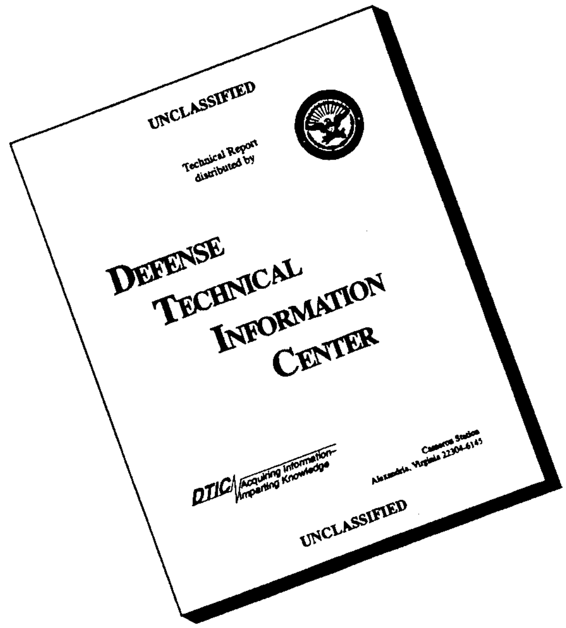


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An interest in the early fielding of the Long Life Ration Packet (LLRP) to meet unique Service requirements resulted in this Short Term Project with objectives of size minimization and assembly cost reduction. Many of the individual food items were previously used in other rations. however. the sizes and shapes of the items for the previous rations have not been modified to optimize the bulk packing density for this ration. Testing the eight sample menu items. it was demonstrated how sequence of packing and component shape and size can be considered in designing the Packet. The best answer found generated a 15% reduction in total package volume. Five alternative LLRP assembly methods were described and evaluated. Manual placement of components into a Packet bottom formed in a horizontal form/fill/seal packaging line gave the lowest assembly costs at production levels of 1 to 10 million LLRPs/year. Recommendations are also included regarding the shapes and sizes of the individual LLRP components.

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# 1.0 CRAMTD Final Report STP #9
# Results and Accomplishments

## 1.1 Introduction and Background

An interest by the military in the early fielding of the Long Life Ration Packet (LLRP) to meet unique Service requirements resulted in this Short Term Project with objectives of size minimization and assembly cost reduction. Many of the individual food items were previously used in other rations; however, the sizes and shapes of the items for the previous rations have not been modified to optimize the bulk packing density for this ration. While the DPSC and CRAMTD emphasis is more on processing than on configuration or size, in the case of LLRP, the sizes and shapes may affect the configuration of tooling. Therefore, there is a need to review the component sizes, shapes, and even packaging materials to optimize the cubic volume of the finished ration to be carried by the user, or to be placed in storage.

## 1.2 Results and Conclusions

Testing the eight different sample menu items, it was demonstrated how sequence of packing and component shape and size can be considered in designing the meal bag. The practical sizes for the bag to accommodate all the menus were determined, as was the best sequences and locations of the components. Optimal sizes of the packet were sought considering some possible best shapes of the components. The best answer found generated about 15% reduction in total package volume over the current meal bag.

Five alternative LLRP "assembly" or packaging methods were described and evaluated. Both manual and robotized assembly operations were examined. Daily production rates were estimated which may be used to determine aggregate worker-hour for a given demand level. A traditional economic analysis was performed to evaluate the sensitivity of unit assembly costs to changes in demand and labor rates. The economic analysis suggests that for demand levels of 1, 5, and 10 million LLRPs/year, an automated horizontal form/fill/seal line with manual laborers is a very attractive technology.

## 1.3 Recommendations

In the following, some recommendations are provided in regard to the shapes and sizes of the LLRP components:

### 1. Individual specifications for the components

Through the study, it was found that it would be beneficial to define separate specifications for each component. For example, the Caramel Bar in the sample menu used was the largest possible size given in the military spec (7" length and 3¼" width inside dimensions for Candy Packet), while its net size is only 4¾" in length and ⅞" in width. A similar case was found for the entree packet. It was noticed that such excess seal allowances require unnecessary volume in the meal bag/tray.

**2. Vacuuming the tray**

To further reduce the total volume of the packet, it may be useful to evacuate the air from or vacuum seal the meal bag. On the form-fill-seal line for CRAMTD, such vacuuming may be easily accommodated in the sealing station.

**3. Reshaping the entree pouch**

Considering the possible changes in the net shapes of the components, the biggest component, the entree pouch, is the best candidate to be considered for reducing the volume. A desirable shape of the entree is flat and rectangular, which may reduce the overall volume by allowing a flatter meal bag. A possible modification is as follows: the freeze-dehydrated entree is packed into the mixing bag with a fully open size of 5½" x 3½" x 8". It is flattened down to the height of 1½" giving a rectangular shape in dimension of 6½" x 3¾". The mixing bag then goes into the entree pouch.

**4. Application to MRE**

The benefits of horizontal form/fill/seal line assembly could also be applicable to MRE. It was recommended that the second phase be redirected to identifying a suitable MRE flexible bag and demonstrating the assembly advantages.

# 2.0 Program Management

Originally, there were two phases in this STP with a duration of 12 months. It was later decided to end the project before proceeding to the second phase. The project officially began on January 2, 1992 and the Phase I Report was completed and forwarded to the Program Manager on November 16, 1992. The specific tasks accomplished in this STP are listed in Figure 1 Appendix 4.1.

Detailed objectives, statement of work, and CRAMTD personnel responsibilities are described in the Technical and Cost Proposals for STP #9.

## 2.1 Summary of Progress

- Five alternative assembly methods were evaluated using computer simulations. The advantages and disadvantages of each alternative were listed. Manual CRAMTD had the lowest cost per LLRP.
- The major factors affecting the overall volume of the LLRP package were identified as (1) the sequence of packing the components and corresponding locations, and (2) the shapes of individual components.

- Two different packages were studied: Preformed meal bag (meal bag) as is used in current LLRP and a formed meal bag bottom (tray) with subsequent sealed top such as would be available on a form-fill-seal line. Rules for sequencing components were developed for each package.
- The process for achieving minimum volume for a sample menu was studied focusing on the best shape of the major components.
- Phase I was completed in November, 1992, a decision was made not to proceed with Phase II due to uncertainties related to the LLRP product.

# 3.0 Short Term Project Activities

## 3.1 Technology Review

The Long Life Ration Packet (LLRP) is based on freeze-dried items rather than thermostabilization. A brief historical perspective of freeze drying operations is provided in the attached Technical Working Paper (TWP #66 - Appendix 4.3). Freeze drying became very popular in the 1980s with growing consumer interest in personal convenience of food preparation. Also, the increased popularity of camping and hiking has led to a renewed interest in freeze-dried foods. Freeze drying offers quality and variety in over 400 different food items. In the United States, Oregon Freeze Dry Foods Inc. has supplied U.S. Agencies for the past 25 years with many diverse products including long range patrol rations for the U.S. Marines.

## 3.2 Menu Items (3.3.2)

Natick Research, Development & Engineering Center (NRDEC) provided a listing of eight menus under consideration (See TWP #66). Each LLRP consists of seven individual components which are sealed with a trilaminate material containing aluminum foil. The individual components are then placed inside a polyethylene meal bag with a density of 0.910 to 0.929 g/cm3. The inside width of the bag is to be not less than 7 inches and not more than $7\frac{5}{8}$ inches and the inside length is to be $11\frac{7}{8}$ inches (+ or - $\frac{1}{8}$ inch). The seven components are to be "arranged in such manner as to occupy the minimum amount of space while maintaining a flat configuration" (MILSPEC "Assembly of Long Life Ration Packet", p. 8). Excess air is to be manually expelled prior to heat sealing to allow tight packing of the meal bags. Sixteen filled and sealed meal bags will then be placed into a shipping container (fiberboard carton).

## 3.3 Sizes and Shapes (3.3.3)

The study of the shapes and sizes of the components in the LLRP packet focused on identifying the key factors for reducing the packaging volume. The two key factors to be considered are the sequence of packing the components and the individual shape and size of each component for a given packing sequence and component location. The best answer found generated about 15% reduction in total package volume over the current meal bag.

### 3.3.1 Individual Specifications for the Components

It was found that defining separate specifications for each component would be beneficial. For example, Caramel Bar in the sample menu used the largest Candy Packet possible (7" length and 3¼" width inside dimensions) while its net size is only 4¾" length and ⅞" width. A similar case was found for the entree packet. Such excess seal allowances require unnecessary volume in the meal bag.

### 3.3.2 Vacuuming the Tray

To further reduce the total volume of the packet, it may be useful to evacuate air from the meal bag. On the form-fill-seal line, such vacuuming may be easily accommodated in the sealing station.

### 3.3.3 Reshaping the Entree Pouch

The entree pouch, the largest LLRP component, is the best candidate to be considered for reducing the volume. A flat and rectangular entree shape would reduce the overall volume by allowing a flatter meal bag. A possible modification flattens the thickness to 1½"and 7½" by 5".

## 3.4 Packet Material (3.3.4)

Two different packages were assumed: Preformed meal bag as is used in the sample received from CINPAC, and a formed meal bag bottom (tray) with subsequent sealed top which is considered as an alternative in a form-fill-seal line.

## 3.5 Preliminary Assembly Costs (3.3.5)

### 3.5.1 Assembly Scenarios

Five alternate assembly scenarios were defined and evaluated:

1. Manual
2. Manual Advanced
3. Semi-Automatic
4. Manual CRAMTD (horizontal form/fill/seal method with manual laborers)
5. Advanced CRAMTD (horizontal form/fill/seal method with robot and computer vision system)

#### 3.5.1.1 Manual

Manual LLRP assembly involves a workstation with a table in which components in bins surround the worker in a U-shaped design. The worker will reach for each item, starting on the right side of the layout, and work through the U following a specific assembly sequence. At the end of the U, it is assumed that there is a tote for storing filled meal bags. The same worker who transports the totes to the sealer will also supply the workstation with components.

#### 3.5.1.2 Manual Advanced

In manual-advanced LLRP assembly, it is assumed that there are a number of independent workstations connected by a conveyor. Cartons of components are placed in gravity flow racks which are mounted on the conveyor. Workers reach into the cartons while seated and pick and pack components. After each component is placed in the meal bags, the bag is placed on the conveyor which carries it to the next station.

#### 3.5.1.3 Semi-Automatic

For this scenario, it is assumed that there are workstations along both sides of the conveyor. The components for each worker are loaded onto the conveyor by an automatic dispensing station. This specially designed station would contain seven chutes where the components are stocked by a worker. Computer control would direct the picking mechanism to the appropriate chute for each component. A timing mechanism would trigger the release of the components in a predetermined sequence. The components would be delivered to each worker in a "kit" containing all seven components in a predefined assembly sequence. The worker would then remove the components from the conveyor and place them into a meal bag. The meal bags would be placed into a tote which would be moved to the inspection and sealing station by a utility worker.

#### 3.5.1.4 Manual CRAMTD

The horizontal form/fill/seal machine developed by CRAMTD for MRE pouch production is used as the starting point for advanced LLRP assembly. In this scenario, manual laborers are used to fill the formed meal bag bottom (tray). Similar to the Manual Advanced scenario, gravity flow racks are utilized to present cartons of components to the workers who perform the pick and place operations. It is postulated that the horizontal, open presentation of a partially formed meal bag will enable greater flexibility and accuracy in the placement of components. This scenario allows inspection and sealing of the meal bags to occur on-line, rather than off-line.

#### 3.5.1.5 Advanced CRAMTD

In this scenario, the modified CRAMTD pouch line is assumed but, rather than using manual workers to fill the formed meal bag bottom (tray), a robot with a computer vision setup is used. The robot is assumed to be able to pick up randomly oriented products and place them on stationary or moving locations, at rates comparable to touch labor. Prior to picking up the components, they would be placed on the feeder conveyor using specially designed dispensers. Similarly to the previous scenario, this scenario also allows inspection and sealing of the meal bags to occur on-line, rather than off-line.

### 3.5.2 Simulation Models

Simulation was used to create strategic models of each alternative to evaluate assembly rates, aggregate labor requirements, alternative demand schedules, quality control plans, and sealing and cartoning rates. These models were then used to evaluate the economics of labor, equipment, and packaging materials for alternative assembly methods. Technical Working Paper 65 describes these simulation models in detail (Appendix 4.2).

### 3.5.3 Costs

Traditional cost analyses were performed to compute preliminary LLRP assembly costs. A summary of cost data for the three most realistic scenarios, Manual, Manual Advanced, and Manual CRAMTD are provided in the table below. Technical Working Paper 65 provides further details.

| | Annual Demand | | |
|---|---|---|---|
| | 1 million | 5 million | 10 million |
| Manual | $.12/LLRP | $.12/LLRP | $.12/LLRP |
| Manual Advanced | $.12 | $.11 | $.11 |
| Manual CRAMTD | $.10 | $.08 | $.08 |

# 4.0 Appendix

4.1 Figure 1 - CRAMTD FTR #9 Time and Events Milestones

4.2 Figure 2 - Economic Evaluation of Assembly Methods For Long Life Combat Rations (TWP 65)

4.3 Figure 3 - Evaluation of Sizes and Shapes for Long Life Combat Rations (TWP 66)

Appendix 4.1

# Fig. 1 - CRAMTD Short Term Project #9
## Long Life Ration Packet

## Projected Time & Events and Milestones

| Phase | Description of Specific Task | Section Ref. # | 1992 J | F | M | A | M | J | J | A | S | O | N | D | 1993 J | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | Literature Search | 3.3 | | | | | | | | | | | | | | |
| | - Industry Survey | 3.3.1 | ↑ | | ↓ | | | | | | | | | | | |
| | - Menu Items | 3.3.2 | | | | ↑ ↓ | | | | | | | | | | |
| | - Sizes and Shapes | 3.3.3 | | | | | ↑ | | ↓ | | | | | | | |
| | - Packet Material | 3.3.4 | | | | ↑ | ↓ | | | | | | | | | |
| | - Preliminary Assembly Costs | 3.3.5 | | | | | ↑ | | ↓ | | | | | | | |
| | - Interim Technical Report (Quarterly) | 3.3.6 | | | ♦ | | | ♦ | | | ♦ | | | ♦ | | |
| | - In-Process Review | 3.3.6.1 | | | | | | ♦ | | | | | | | | |
| II | Develop Methods and Equipment | 3.4 | | | | | | | | | | | | | | |
| | - Fabricate Equipment | 3.4.1 | | | | | | | | | ⇧ | | ⇩ | | | |
| | - Component Aquisition | 3.4.2 | | | | | | | | | ⇧ | ⇩ | | | | |
| | - Equipment Installation | 3.4.3 | | | | | | | | | | | ⇧ ⇩ | | | |
| | - Production Aids | 3.4.4 | | | | | | | | | ⇧ | | ⇩ | | | |
| | - Limited Production | 3.4.5 | | | | | | | | | | | | | ⇧ ⇩ | |
| | - Cost/Benefit Analysis | 3.4.6 | | | | | | | | | | | | | | ⇧ ⇩ |
| | - Demonstration | 3.4.7 | | | | | | | | | | | | | ⇧ | ⇩ |
| | - Final Technical Report | 3.4.8 | | | | | | | | | | | | | | ⇩ |
| | - Review | 3.4.8.1 | | | | | | | | | | | | ◊ | | |

**LEGEND:**

⇧ = Projected Start
↑ = Start
⇩ = Projected Completion
↓ = Completed
◊ = Decision Milestone
♦ = Completed Decision Milestone

Revised 03/26/93

# COMBAT RATION
# ADVANCED MANUFACTURING
# TECHNOLOGY DEMONSTRATION
# (CRAMTD)

## Economic Evaluation of Assembly Methods for Long Life Combat Rations

**Technical Working Paper (TWP) 65**

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**April 1993**

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# ECONOMIC EVALUATION OF ASSEMBLY METHODS FOR LONG LIFE COMBAT RATIONS


## Abstract

This paper evaluates alternative assembly methods for Long Life Ration Packets (LLRPs) which contain freeze-dried components for consumption by military personnel. Five alternative LLRP "assembly" or packaging methods are described and evaluated. Both manual and robotized assembly operations are examined. Daily production rates are estimated which may be used to determine aggregate worker-hours for a given demand level. A traditional economic analysis is performed to evaluate the sensitivity of unit assembly costs to changes in demand and labor rates. The economic analysis suggests that for demand levels of 1, 5, and 10 million LLRPs/year, an automated horizontal form/fill/seal line with manual laborers is a very attractive technology. This technical working paper provides a methodology for evaluating labor, equipment, and packaging issues in the system design of freeze-dried assembly methods.

# ECONOMIC EVALUATION OF ASSEMBLY METHODS FOR LONG LIFE COMBAT RAITIONS

## I. INTRODUCTION

The Combat Ration Advanced Manufacturing Technology Demonstration (CRAMTD) is a research project sponsored by the Defense Logistics Agency to examine the use of computer integrated manufacturing (CIM) techniques to improve the production rate of combat rations for both military and commercial markets. An improvement in the production process for combat rations will intensify the industrial mobilization capability of the United States during times of military conflicts, such as the recent Desert Storm Operation.

The CRAMTD project is investigating the automation of both tray pack and pouch lines. Sample menu items include beef stew, beef chunks in gravy, and ham slices. Although primarily focusing on thermostabilized products or "Meals Ready to Eat (MREs)", the military is also interested in packaging freeze-dried products. Due to the uniqueness and cost of equipment for the freeze drying process, "production" of freeze-dried components will be accomplished by a subcontractor that routinely engages in freeze drying operations. The purpose of this study is to examine alternative "assembly" methods for packaging the freeze-dried rations which are termed Long Life Rations Packets (LLRPs). The LLRP is an experimental product that the military is interested in fielding to meet unique Service requirements.

In the next section a brief historical perspective of freeze drying operations is provided. This survey also includes a listing of the proposed menu items for LLRPs. Alternative assembly methods under consideration are described. Traditional economic analyses are then used to develop preliminary assembly costs.

## II. LITERATURE SURVEY

Dalgleish (1990) provides detailed discussions of both the evolution and technical procedures of freeze drying operations. After World War II there was a realization by the various military organizations that there was a compelling need to establish large-scale food production systems to supply military personnel. The technical advantages of freeze drying are that it is performed at relatively low temperatures and there is no shrinkage as with hot-air drying, so the light and porous components retain their shape and dimensions. Since these individual components can be easily reconstituted to a close resemblance to the original in color, texture, odor, and flavor, freeze drying of foodstuffs was considered to be an attractive technology.

In 1948 the Commonwealth Advisory Committee on Defense Science (CACDS) in England realized the importance of continuing to research alternative food production systems. Dehydration was considered as a promising food process since it had made significant contributions during the war; however, its limitations were also becoming apparent. Researchers in Denmark had developed a novel vacuum-drying process that was utilized in Norway after the war for the production of dried fish. After examining this facility, representatives of the United Kingdom initiated a plan to construct an experimental factory in Aberdeen, Scotland. With the Ministry of Food spearheading the project, the plant was constructed, and it operated for approximately 10 years. The plant was closed in 1961 but not before developing an Accelerated Freeze Drying (AFD) Process. With the AFD process, products 15 mm in thickness could be dried in less than an 8-hour shift as opposed to 48 hours using earlier freeze drying methods. The Aberdeen project experimented with the dehydration of many individual components and created a number of complex recipes for soups, sauces, steaks, fish, etc..

Due to political and socio-economic pressures, the Ministry of Food abandoned the Aberdeen project and private firms began to investigate freeze drying operations. Food companies in Denmark, Ireland, Italy and Germany designed and developed freeze drying plants worldwide. Some engineering modifications to the basic processing equipment for vapor disposal also emerged. Some of the leading companies in this era were Atlas, Vickers Armstrong, Leybold, and Erin Foods. Erin Foods opened some freeze drying factories in America in the mid-1960s.

During the 1970s new techniques emerged among commercial freeze drying companies. During the early days of freeze drying it was difficult to determine when a product reached the stage of being fully and properly processed, so allowances of up to an extra 100% cabinet time were typically permitted. Numerous mechanical devices and processing techniques for controlled heating were soon developed.

Freeze drying became very popular in the 1980s with growing consumer interest in personal convenience of food preparation. Also, the increased popularity of camping and hiking has led to a renewed interest in freeze-dried foods. Astronauts have been trained to use salivation as a means of adequately preparing a number of substances for consumption (Dalgleish, 1990). Freeze drying offers quality and variety in over 400 different food items (Duxbury, 1988). In the United States, Oregon Freeze Dry Foods Inc. has supplied U.S. agencies for the past 25 years with many diverse products including long range patrol rations for the U.S. Marines. As Dalgleish (1990) concludes "the substantive reasons for freeze drying foodstuffs remain investment in (a) personal convenience of stored true wealth, (b) rapid realizability of staple necessities, and (c) security from supra-national calamity" (p. 218).

## 2.1 Menu Items

Table 2.1 displays a list of eight menu items that have been proposed for the military. Each LLRP consists of seven individual components which are sealed with aluminum foil. The individual components are then placed inside a polyethylene meal bag with an inside width of approximately 7 inches and an inside length of approximately 12 inches. The seven components are to be "arranged in such a manner as to occupy the minimum amount of space while maintaining a flat configuration" (MILSPEC "Assembly of Long Life Ration Packet", p. 8). Excess air is to be expelled prior to sealing with heat to allow packing of the meal bags. Sixteen filled and sealed meal bags will then be placed into a shipping container (cardboard carton). It has been estimated that LLRP has a shelf life of approximately 10 years.

## III. RESEARCH METHODOLOGY

This design methodology models and evaluates five different assembly scenarios:

1) Manual
2) Manual Advanced
3) Semi-Automatic
4) Manual CRAMTD (horizontal form/fill/seal method with manual laborers)
5) Advanced CRAMTD (horizontal form/fill/seal method with a robot and computer vision system).

Simulation is used to create "strategic" models of each alternative which may be used to evaluate assembly rates, aggregate labor requirements, alternative demand schedules, quality control plans, and sealing and cartoning rates. In particular, the simulation models enable an analyst to consider the probabilistic behavior of an assembly system by considering stochastic data. The probabilistic production rates from the simulation models may be compared with deterministic rates to ascertain if there are any significant deviations. If not, then the deterministic rates may be used to quickly "benchmark" or to "approximate" production output.

The LLRP production rates are then used to evaluate the economics of labor, equipment, and packaging material for alternative assembly methods. Preliminary operations costs/unit are calculated for selected LLRP assembly systems. This design methodology results in guidelines for Instrumented Production Modules (IPMs) which suggest equipment specifications for a given set of operating assumptions.

### 3.1 Simulation Models

Discrete event simulation has been used by both industry and academia to model many diverse, complex production systems. Simulation enables an analyst to emulate a physical system using a computer model to perform parametric sensitivity analysis (i.e. "what-if gaming"). The user can then make certain inferences based upon the laws of probability from the computer model regarding the performance of the actual operating system. The simulation model enables an analyst to evaluate the probabilistic behavior of a system. The LLRP simulation models, for instance, consider probability distributions for assembly and transport times.

The simulation models in this research are used to describe steady state assembly operations as opposed to transient or start-up operations. In reality, some time is required to "ramp-up" a production system to the point where the system is "loaded" with a steady supply of components to work stations. These simulation models represent "high level", "strategic", or "concept models", since very detailed models of actual operating systems could not be obtained.

This scenario-based analysis considers manual filling to be the baseline case. Some variations of manual filing that utilize production aids (e.g. fixtures, conveyor, automatic dispenser, gravity flow racks, etc.) are also considered. For the advanced technology scenarios, the horizontal form/fill/seal machine developed at CRAMTD for MRE pouch products appears to be an attractive starting point for packaging LLRPs.

### 3.2 Simulation Inputs for All Models

The following comprise the required inputs for all the simulation models used in this research:

1. Due dates for menu items. Three different menu items may be scheduled concurrently.

2. Demand for each menu item.

3. All LLRPs are inspected prior to sealing to determine if they have been properly filled. If there is an error, the LLRP is reworked.

4. For post-sealing, the sampling plan involves the inspection of one LLRP every 20 minutes over an 8 hour work day. If 8 defective LLRPs are found, production will be stopped for the day and the lot rejected.

5. At the end of the filling, inspection, and sealing operations, the simulation models count the number of finished cartons and pallets.

The demand level is an important factor in the simulation analysis since it directly determines the number of aggregate worker-hours for each assembly method. Unfortunately, since the LLRP is an experimental product, past production and contract experience is not available. Three levels of demand are assumed in the simulation scenarios that represent short, medium and long production runs. The assumed demand levels are 1, 5, and 10 million LLRPs per year.

Note that a distinction may be made between the "assembly rate" and the "production rate". The "assembly rate" refers to those operations that are involved with filling a meal bag. The "production rate" includes the inspection, sealing, and cartoning rates, as well as the assembly rate. The production rate refers to product that is completed and ready for shipment.

## IV. PRELIMINARY ASSEMBLY COSTS

In this section the five alternative LLRP assembly scenarios under consideration are discussed in more detail. Following these descriptions is a traditional economic analysis of the three most realistic scenarios.

### 4.1 Scenario 1: Manual Bench Assembly

This scenario assumes that manual LLRP assembly involves a workstation with a table in which components in bins surround the worker in a U-shaped design as depicted in Figure 4.1. The worker will reach for each item, starting on the right side of the layout and work through the U following a certain assembly sequence. For example, for the beef stew menu (LLRP Menu #2), this sequence is:

1. Beef Stew Packet
2. Accessory Packet
3. Chocolate Covered Cookie
4. Caramel
5. Granola Bar
6. Cocoa Beverage Powder
7. Spoon.

At the end of the U, it is assumed that there is a tote for storing filled meal bags. The same worker who transports the totes to the sealer will also supply the workstation with components (i.e. an infinite supply is assumed in the simulation model).

It must be emphasized that the above workstation layout and assembly sequence are not based on actual operations, since the CAFT LLRP research team was unable to observe assembly plant operations. The layout and sequence represent just one possible design based upon classical industrial engineering and motion economy principles. Note that the work envelope surrounding the worker considers the minimum, maximum, and ideal reach capability for a worker. This will be used as a starting point when developing a work envelope for robotized assembly.

One of the required inputs for the simulation model for manual LLRP assembly is the cycle time per worker. A predetermined time system (PTS) was used to develop an estimate of manual assembly time. There are many predetermined work measurement systems available: MTM, the Work Factor series, MODAPTS, and MOST are some of the more popular systems. In these systems a time estimate can be constructed by logically aggregating the individual tasks that comprise a job. Time values have been tabularized based on very detailed and sophisticated micro-motion studies. These time values are referred to as Time Measurement Units (TMUs). TMUs are easily converted to minutes or hours using a conversion factor of .0006 min/TMU. In this predetermined time method, 1 TMU is defined as 0.00001 hour.

For the LLRP study, the Maynard Operation Sequence Technique (MOST) which was developed by Zandin (1980) was selected due to its appropriateness and ease of application. One of the macro-models in MOST is referred to as a "General Move Model". In a general move, an object is simply picked up and moved freely through space. There is also a "Controlled Move Model" where a fixed path must be followed and resistance is encountered when moving an object.

The "General Move Model" is described as follows:

A B G \ A B P \ A

where

A - Action Distance
B - Body Motion

G - Gain Control
P - Place.

The first three parameters are used to model "getting" an object - there is an action distance, there may be body motion, and one must gain control of an object before moving it. The second three parameters are used to model "moving" an object - there is an action distance, body motion may be applied, and some placement is usually required. The final parameter is used to indicate an additional action distance to return to the initial work position. Once a motion has been analyzed as a general move, the model is predetermined. Parameter variants, or subscripts, have been developed to differentiate grades of comparison.

Manual LLRP assembly may be decomposed as follows:

| | | |
|---|---|---|
| Worker reaches for component, moves it to the meal bag, and inserts it into the meal bag while sitting on a chair. | $(A_1\ B_3\ G_1\ A_1\ B_0\ P_3\ A_1)\ 7$ | 700 TMUs |
| Worker places a completed meal bag in a tote. | $(A_1\ B_3\ G_1\ A_1\ B_0\ P_1\ A_1)$ | 80 TMUs |
| | TOTAL: | 780 TMUs |

Since there are seven components per LLRP the first general move model has a frequency of 7 outside the parentheses. The subscripts are simply added, multipled by the frequency, and then multipled by a factor of 10 to compute the TMUs.

Further analysis of the above predetermined time model reveals that it should be easy for the worker to "simultaneously" grasp the last two components (i.e. the cocoa beverage powder and the spoon) and then to concurrently place them into the meal bag. Such a method uses motion economy principles by utilizing momentum. Thus, the first general move model would have a frequency of 6 outside the parentheses (since there are now 6 "reaches") resulting in 600 TMUs. When aggregated with the second general move model, the total time for manual bench assembly is 680 TMUs.

Estimated Time:

680 TMUs x (.0006 min/TMU) = .408 minutes/LLRP

The above time represents a normal time that must be adjusted for work allowances for fatigue, personal needs, and unavoidable delays. An aggregate allowance of 40% is assumed for manual LLRP assembly. Thus, a standard time is computed as:

.408 min/LLRP x (1.40) = .57 min/LLRP

or 1.75 LLRPs/minute.

## 4.2 Scenario 2: Manual Advanced Assembly

In manual-advanced LLRP assembly, it is assumed that there are a number of independent workstations connected by a conveyor as portrayed in Figure 4.2. Cartons of components are placed in gravity flow racks which are mounted on the conveyor. Workers reach into the cartons while seated and pick and pack components. An additional assumption is that there is an infinite supply of empty meal bags at the first station. The first component is placed in the bag, and then the bag is placed on the conveyor. The conveyor then transports the meal bags through the remaining stations. Each worker at a station adds one item to the meal bag (the last worker also adds the spoon) following the same assembly sequence as in manual bench assembly.

The assembly rate for this scenario is assumed to be 10 LLRPs/minute. Since the meal bag is transported by conveyor to each station along the assembly line, the 80 TMUs of time that are used to place a filled meal bag into a tote for the bench assembly method are eliminated. In the assembly line scenario, it is assumed that at the sixth station the worker "simultaneously" places the last component (e.g. cocoa) and the spoon into the meal bag. Therefore, the following time estimate is developed:

600 TMUs/LLRP x .0006 min/TMU = .36 min/LLRP.

Since there are 6 stations along this assembly line, the average assembly time at each station is computed as:

.36 min/LLRP / 6 stations = .06 min/LLRP/station.

The same 40% allowance for fatigue, personal needs, and unavoidable delays are used as in bench assembly. Thus, the standard time per station is estimated as:

.06 min/LLRP/station x 1.4 = .084 min/LLRP/station.

In assembly line work, the slowest operation determines the production or assembly rate. In this case, using the average station time of .084 min/LRP we have:

60 min/hr / .084 min/LLRP = 714 LLRPs/hr

or 11.9 LLRPs/min

which is approximated to 11 LLRPs/min if considering "integer" production. Note that for <u>bench assembly with six workers</u>, the estimated assembly rate per hour is:

6 workers x 1.75 LLRPs/min = 10.5 LLRPs/min

or .095 min/LLRP.

Therefore,

60 min/hr / .095 min/LLRP = 632 LLRPs/hr

or 10.5 LLRPs/min

which is approximated to 10 LLRPs/min for a bench assembly system with six workers.

One of the principal advantages of this assembly line scenario is that a filled meal bag may be directly transported to inspection and sealing stations. In manual bench assembly, a utility worker must carry the filled totes to the inspection and sealing stations. The LLRP manual assembly line provides more continuity of material flow and a higher level of integration than bench assembly.

Once the meal bag has been filled, it is transported by conveyor to an inspector. There is a probability that during the course of an 8-hour shift that a component or components may inadvertently not be placed in the meal bag as it passes by a station. Thus, the bag would need to be "reworked" off line. One possible method of determining if all seven components have been placed in the bag is to weigh the filled bag at the inspection station. If the weight of the filled bag does not fall within an acceptable range, then there is a probability that a component(s) are missing. Acceptable bags are transported by conveyor to the sealing and inspection stations and then cartoned.

### 4.3 Scenario 3: Semi-Automatic Assembly

Figure 4.3 displays a possible semi-automatic LLRP assembly scenario where it is assumed that there are workstations along both sides of a conveyor. The components for each of the workers are loaded on to the conveyor by an automatic dispensing station. This specially designed dispensing station would contain seven chutes where the components are stocked by a worker. Computer control would direct the picking mechanism to the appropriate chute for each component. A timing mechanism would trigger the release of the components and they would be channeled or pushed into two parallel lines. The components would be released according to a predetermined assembly sequence. It is assumed that there is a continuous supply of components to the stations along the conveyor.

In this scenario each worker at a station now receives a "kit" of seven components which arrive in a predefined assembly sequence. There are work counters adjacent to the conveyor. These counters contain a supply of meal bags and a bag holder design that would enable the worker to hold an open meal bag in a vertical position (perhaps a "funnel" shaped design). The worker would then remove the "kit" of seven components from the conveyor to the counter and place them into the meal bag. Once the meal bag has been filled with its seven components, it is removed from the bag holder, and then placed into a tote that sits on the floor. A utility worker is available for picking up the filled totes and transporting them to the inspection and sealing station.

The assembly rate for this scenario is assumed to be 9 LLRPs/minute. In this scenario time must be allowed for removing the "kit" of seven components from the conveyor to the work counter. Using a MOST "General Move Model", this time is estimated as:

| | | |
|---|---|---|
| Worker removes "kit" of 7 components from conveyor to work counter. | A B G A B P A<br>1 3 1 1 0 0 1 | 70 TMUs |

When filling the meal bag, it is assumed that the worker can "simultaneously" pick up the last component (e.g. cocoa) and the spoon and then place them in the meal bag. Time must also be allowed for the worker to remove the filled meal bag from the bag holder and place it in the tote. The time of 80 TMUs from the bench assembly method is included and the total assembly time per worker is estimated as 750 TMUs (600 + 70 + 80). Thus,

750 TMUs x .0006 min/TMU = .45 min/LLRP.

The standard time with a 40% allowance for fatigue, personal needs, and unavoidable delays is:

.45 min/LLRP x 1.4 = .63 min/LLRP

or 1.59 LLRPs/min.

Since the semi-automatic assembly scenario depicts 6 workers along both sides of a 48" wide conveyor, the assembly rate for this system is:

6 workers x 1.59 LLRPs/min = 9.54 LLRPs/min

or .105 min/LLRP.

Therefore,

60 min/hr / .105 min/LLRP = 571 LLRPs/hr

or 9.52 LLRPs/min

which is approximated to 9 LLRPs/min for the semi-automatic assembly scenario with six workers.

Recall that the simulation models are used to analyze steady state operations and not transient operations. Thus, once the system has been operating for some time, it is assumed that each station has a steady supply of components. Such a system results in "paced productivity". In manual bench assembly, the utility worker must move between the benches resupplying components. With automatic dispensing of components, the utility worker only needs to restock the dispensing unit from a central location, thus minimizing restocking time and travel distance. A moveable replenishment shelf in the dispenser would simplify restocking of product. Due to the high capital cost and re-engineering costs associated with an automatic dispensing unit, this scenario was eliminated from the economic analysis.

4.4 Scenario 4: Manual CRAMTD LLRP Assembly

The horizontal form/fill/seal machine developed by CRAMTD for MRE pouch production is used as a starting point for advanced LLRP assembly and is exhibited in Figure 4.4. In this scenario, manual laborers are used to fill a formed meal bag. As in scenario 2, gravity flow racks are utilized to present cartons of components to the workers who perform picking operations. This assembly configuration uses a packaging machine with an automatic controller. It is postulated that the horizontal, open presentation of a partially formed meal bag will enable greater flexibility and accuracy in the placement of components. As automated component handling becomes available, even greater advantage can be taken of this open access. Considerable flexibility exists regarding mold shape, size and forming conditions. Once the packaging material and package dimensions are selected, appropriate tooling can be specified along with the required operating conditions (temperature/pressure for both forming and sealing). The capability to seal either vacuum or modified atmosphere provides an opportunity to immobilize components within the package and/or to extend the overall storage life of the ration.

It is required to modify the MRE setup for the form/fill/seal machine so that LLRP assembly could be performed. The retrofit changes require the purchase of forming frames, filler plates, seal support frames, chamber lid and a total seal plate to accommodate the larger sized meal bag. A complete new formset could also be purchased. The forming station for MRE pouch production forms six pouches at a time into two rows of six pouches each. These stations are connected by a conveyor. Every time the conveyor indexes, it moves through a length of three pouches. For LLRP assembly the forming station will form two meal bags at a time.

For this scenario it is assumed that 2 LLRPs index every 10 seconds and that there are three workers filling components. The assumed assembly rate for this scenario is 11 LLRPS/min. The first two workers each place two different components of a menu item on top of the bottom layers of the meal bags. The last worker places 2 different components and the spoon. Thus, at the end of the line, all 7 components have been placed into 2 side-by-side forming trays.

The assembly method for the first two stations is described below:

| | | |
|---|---|---|
| Worker reaches for two components simultaneously, moves them to the forming trays, and places them in the trays while sitting on a chair. This sequence is repeated twice. | $(A_1\ B_3\ G_1\ A_1\ B_0\ P_3\ A_1)\ 2$ | 200 TMUs |

At the third station the worker would pick up the spoon and one component with one hand while using the other hand to pick up another component simultaneously. The estimated assembly time essentially remains the same since this general move does not require a high level of difficulty. Thus, the estimated time for this "assembly line" is based on the time for the slowest station which determines the work pace for the entire line. This time is estimated as:

$$200 \text{ TMUs/station} \times (.0006 \text{ min/TMU}) = .12 \text{ min/station.}$$

The same 40% allowance for fatigue, personal needs, and unavoidable delays are used as in the previous manual assembly methods. Thus, the standard time for each station is estimated as:

$$\frac{.12 \text{ min/station} \times 1.4}{2 \text{ LLRPs/station}} = .084 \text{ min/LLRP.}$$

The assembly rate for the manual CRAMTD LLRP line is estimated as:

60 min/hr / .084 min/LLRP = 714 LLRPs/hr

or 11.9 LLRPs/min

which is approximated to 11 LLRPs/min if considering "integer production". This assembly rate is then used to determine the cycle time for the horizontal form/fill/seal machine. Since there are two trays being filled side by side, the index time for the horizontal form/fill/seal machine is estimated as 10 seconds.

A factor to consider in the use of horizontal form/fill/seal machines is the cost of the packaging material. Blanthorn, et al. (1988) provide cost estimates for MRE pouches of 2 to 3 cents less per pouch when forming pouches. It is assumed that there is more labor involved in handling preformed pouches. The form/fill/seal machine would require slightly less labor as to reloading the roll stock. For purposes of this study, it is assumed that the roll stock bag costs 2 cents less than a preformed bag.

### 4.5 Scenario 5: Advanced CRAMTD LLRP Assembly

In this scenario the modified CRAMTD pouch line is assumed but, rather than using manual workers to fill the meal bags, a robot with a computer vision setup is used. A proposed layout is presented in Figure 4.5. It is further assumed that a robot places components on to the bottom layer of 2 side-by-side meal bags using computer vision to determine component orientation. The technical specifications for the robot under consideration indicate that this robot can pick up randomly oriented products and place them on stationary or moving locations, at rates comparable to touch labor.

As indicated in the layout drawing, specially designed dispensers could be located on either side of a feeder conveyor. This dispenser could contain stacks of components which would be released in groups of seven. Such a production aid would facilitate the "singulating" of components for presentation to the robot's manipulator. According to the specifications, the robot tool performs a continuous-path motion from point "a" to point "b" and back to point "a" (12 inch separation distance) in 1.0 seconds. Since all 7 components will be placed into the forming trays by the robot, the assembly time is 7 seconds. However, in these 7 seconds the robot will be able to fill 2 forming trays simultaneously after some modifications to the end effector.

There are management risks associated with this scenario. The difficult technical issues of dispensing the components, designing a customized end effector, and minimizing the movement of components in the forming trays must be solved before proceeding with this scenario. Assuming that technical solutions can be found, the estimated assembly rate for this scenario is:

$$\frac{7 \text{ seconds}}{2 \text{ LLRPS}} = \frac{60 \text{ seconds}}{X}$$

where X is the production in 60 seconds. Using this proportional analysis, it is estimated that the advanced CRAMTD LLRP assembly rate is 17 LLRPS/min. The index time for the horizontal form/fill/seal machine is thus 7 seconds in this scenario.

As indicated in the layout drawing, after the robot has filled the 2 side-by-side forming trays, the machine indexes and the trays move to the sealing station. A videojet printer could be used to code a date/time stamp and menu information. After the meal bags exit the line, they would be transported to a cartoning area.

After further discussions with CRAMTD Engineers, it was decided that the engineering costs of designing the dispenser, the robot gripper and computer integration would be very high. Thus, it was recommended to eliminate this scenario from the economic analysis.

### 4.6 Hybrid Assembly

Early in the analysis of alternative assembly methods for LLRPs, a "hybrid" assembly method was discussed with CRAMTD engineers that involved a combination of manual and advanced methods. In this scenario the horizontal form/fill/seal machine would be used with some combination of manual workers. However, after considering the very short theoretical cycle time of the robot (7 seconds) to place all 7 components of a menu item into 2 side-by-side forming trays, such a hybrid assembly method is not feasible. Even if the robot should not place all 7 components, the cycle time would be so short that the current configuration of the CRAMTD line could not accommodate the number of manual workers that would be required for such an assembly line method. Thus, this scenario is eliminated from further consideration.

### 4.7 Inspection, Sealing, and Case Packing

Check weighing of all LLRPs is used to determine if the correct number of components have been placed into the bag. Meal bags that do not fall within a specified weight range are directed for "rework". For the first three scenarios, manually operated table top vacuum sealers are used. A proposed layout for the sealing stations is presented in Figure 4.6. A sampling plan is used after the meal bags have been sealed to ensure seal integrity. The cartoning operations are considered to be the same for all scenarios.

### 4.8 Scenario Summary

For the first three scenarios, these rates pertain only to those operations involved in filling meal bags and do not include the inspection and sealing rates. Note that with the horizontal/form/fill/seal machine, a meal bag is sealed as it exits from this integrative process. Thus, the rates for the CRAMTD scenarios include sealing operations. The number of personnel supplying product to the line, termed suppliers, is also indicated.

| Scenario # | Description | Assembly Rates LLRPS/hr | LLRPS/min |
|---|---|---|---|
| 1 | Manual Bench Assembly (6 assemblers, 2 suppliers) | 632 | 10 |
| 2 | Manual Advanced Assembly (6 assemblers, 2 suppliers) | 714 | 11 |
| 3 | Semi-Automatic Assembly (6 assemblers, 1 supplier) | 571 | 9 |
| 4 | Manual CRAMTD Assembly (3 assemblers, 1 supplier) | 714 | 11 |
| 5 | Advanced CRAMTD Assembly (1 robot, 2 suppliers) | 1020 | 17 |

Note that although the assembly rates for scenarios #2 and #4 are the same, the manual CRAMTD method can achieve the rate of 11 LLRPS/min with three less workers than the traditional assembly line method. Assuming an 8-hour workday, these hourly assembly rates may be used to develop daily deterministic assembly rates for each method. These rates are given below:

| Scenario # | Description | Daily Assembly Rates (LLRPS/day) |
|---|---|---|
| 1 | Manual Bench Assembly | 5056 |
| 2 | Manual Advanced Assembly | 5712 |
| 3 | Semi-Automatic Assembly | 4568 |
| 4 | Manual CRAMTD Assembly | 5712 |
| 5 | Advanced CRAMTD Assembly | 8160 |

## 4.9 Simulation Analysis

The above rates are "deterministic" since variability is not considered. Simulation enables an analyst to model filling time variability, conveyor breakdowns, transport delays, and inspection and sealing time variability. The primary outputs from the simulation models are the daily "production rates" that include assembly, sealing, inspection, transport, and cartoning operations for each scenario. The principal objective of using simulation in the LLRP analysis is to determine if the aforementioned sources of variability cause highly significant deviations from the deterministic assembly rates. If not, then the deterministic assembly rates may be used to "benchmark" the daily production rates for each alternative.

Due to the length of some runs (1-2 hours), only one replication for each day's assembly for each alternative was performed. The simulation models have the capability to evaluate a product mix of three different menu items. However, alternative scheduling rules were not evaluated in this research. It is assumed that Earliest Due Date (EDD) scheduling is used and that an order for a menu item is completely finished before switching to another item. The simulation analysis reveals the following:

| Scenario # | Description | Simulated Production Rates (LLRPs/day) |
|---|---|---|
| 1 | Manual Bench Assembly (6 assemblers, 2 suppliers) | 4622 |
| 2 | Manual Advanced Assembly (6 assemblers, 2 suppliers) | 5196 |
| 3 | Semi-Automatic Assembly (6 assemblers, 1 supplier) | 4656 |
| 4 | Manual CRAMTD Assembly (3 assemblers, 1 supplier) | 5280 |
| 5 | Advanced CRAMTD Assembly (1 robot, 2 suppliers) | 8000 |

The simulated daily production rates for the five alternative LLRP assembly methods under consideration include variability for filling, sealing, inspection, transport, and cartoning operations. In general, the deterministic assembly rates are greater than the probabilistic production rates which incorporate variability and processing delays. However, for the level of variability that was introduced into the models (typically plus or minus 5% of the mean), the simulated daily production rates do not highly deviate from what one would reasonably expect from using the deterministic assembly rates to estimate daily production rates. Also, until data is obtained from an actual operating system, it is recommended that the deterministic assembly rates be used to "benchmark" or to "approximate" daily production rates for each of the alternative assembly methods under consideration. These "benchmarks" are summarized below:

BENCHMARK DAILY PRODUCTION RATES

| Scenario | Description | Daily Production Rates (LLRPs/day) |
|---|---|---|
| 1 | Manual Bench Assembly (6 assemblers, 2 suppliers) | 5056 |
| 2 | Manual-Advanced Assembly (6 assemblers, 2 suppliers) | 5712 |
| 3 | Semi-Automatic Assembly (6 assemblers, 1 supplier) | 4568 |
| 4 | Manual CRAMTD Assembly (3 assemblers, 1 supplier) | 5712 |
| 5 | Advanced CRAMTD Assembly (1 robot, 2 suppliers) | 8160 |

## 4.10 Economic Analysis

The economic analysis in this paper focuses on LLRP assembly costs. For each scenario a list of materials handling equipment and production aids has been compiled in Table 4.1. Essentially, this listing provides descriptions of Instrumented Production Modules (IPMs), since the basic assembly configuration is specified which could be independently integrated into an existing plant. Vendors have not been indentified in this paper. The cost for a form/fill seal machine is estimated as $175,000. Since the LLRP is larger than the MRE, a tooling change to the form/fill/seal machine is required. An estimate of $30,000 has been provided for a complete formset with a water cooled forming mold for the LLRP. This comparative economic analysis of alternative LLRP assembly methods focuses on "start-up" assembly that includes labor, equipment, and packaging material costs.

### 4.10.1 General Economic Model

Traditional cost analyses are performed to compute preliminary LLRP assembly costs. The general equation used to compute an after-tax cost (ATC) is:

$$ATC = EUAC_e + [C_l + (C_p * X)] (1-TR)$$

where

- $ATC$ = After-tax cost ($/year)
- $EUAC_e$ = Equivalent Uniform Annualized Cost for equipment ($/year)
- $C_l$ = labor cost ($/hr)
- $C_p$ = packaging material cost ($/LLRP)
- $X$ = production quantity (LLRPS/year)
- $TR$ = tax rate (%).

A useful life of 7 years is assumed with a 5 year class life for all equipment. A tax rate of 40% and an interest rate of 12% is used. A Modified Accelerated Capital Recovery System (MACRS) depreciation schedule is used. It is assumed that packaging material costs are $0.11 and $0.09 per LLRP for preformed and roll stock bags, respectively.

As previously noted, the three most "realistic" scenarios are Scenarios 1, 2, and 4. The daily production rates for these scenarios determines the number of workers that are required to satisfy a given demand level. Labor costs are based on total worker-hours. It is assumed that there is a plant operating constraint of 240 days/year (i.e. all contract orders must be completed within the time constraint). Thus, short-term capacity expansion techniques, such as multiple shifts, multiple lines, more resources, etc. may be required to satisfy the annual demand.

The economic analysis considers demand levels of 1, 5, and 10 million LLRPs/year and labor rates of \$5/hr and \$8/hr.

Cost computations for Scenarios 1, 2, and 4 using a labor rate of \$5/hr are provided in Tables 4.2 - 4.4. A summary of preliminary assembly costs that reflects labor rate sensitivity is given in Table 4.5. The economic analysis reveals that the MANUAL CRAMTD scenario is preferred over the MANUAL and MANUAL ADVANCED scenarios for the demand levels of 1, 5, and 10 million LLRPs/year evaluated at labor rates of \$5/hr and \$8/hr. As the annual demand increases, the preference for the MANUAL CRAMTD scenario becomes stronger. Note that at a labor rate of \$5/hr and an annual demand of 10 million LLRPs, the unit assembly cost for the MANUAL CRAMTD scenario is approximately 33% less than the MANUAL and MANUAL ADVANCED unit assembly costs which equates to an after-tax cost difference of \$400,000. Using a labor rate of \$8/hr and an annual demand of 10 million LLRPS, observe that the MANUAL CRAMTD unit assembly cost is lower than the MANUAL and MANUAL ADVANCED scenarios by 40% and 36%, respectively. The reduced labor requirement of the MANUAL CRAMTD LLRP assembly scenario results in significant cost savings at high production volumes. Since the Tiromat line automatically integrates filling and sealing operations, the labor cost savings are primarily due to the elimination of the need for sealing operators. Table 4.6 presents a summary of the advantages/disadvantages of the five alternative LLRP assembly scenarios under consideration.

## V. FURTHER REMARKS

This paper provides a methodology for the economic evaluation of alternative assembly methods for Long Life Ration Packets. Since actual plant operations were not observed, simulation is used to create alternative "concept models". Labor and equipment configurations, or independent Instrumented Production Modules (IPMs), are evaluated and daily assembly rates are determined. These assembly rates are used in traditional economic analyses to recommend a preferred assembly method for different ranges of demand.

One of the original assumptions in this paper is that there are separate systems for producing and assembling LLRPs. The actual freeze drying process is separate from the assembly operations and the two processes may not even be in close proximity. Thus, extensive logistical costs may be incurred in transporting freeze-dried components from production plants to assembly plants. It is recommended that a study be conducted to investigate the technical feasibility and economics of an integrated production/assembly system if the military intends to increase the production of freeze-dried rations.

It is important to remember that the simulation models are not representations of "real operating systems". Thus, the models have not been validated with actual data. If a very precise operational study is desired, it is recommended that actual data be collected before proceeding with any technical analyses. However, these simulation "concept models" are very useful in the system design phase and may be used to rapidly evaluate a number of alternatives.

With the downsizing of the military, freeze-dried products with their long shelf lifes may become the preferred food source for prepositioned food reserves. Commercial and institutional market opportunities for freeze-dried products will probably expand in the near future due to product diversity and technological advances in freeze drying processing and packaging. This research attempts to provide some economic guidelines for the cost effective design of assembly methods for these rations.

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## LONG LIFE RATION PACKET 1991 ASSEMBLY

AS OF: 10-Feb-92

### MENU 1

Chicken Stew
Cornflake bar
Oatmeal cookie bar
Tootsie roll (4 pks)
Apple cider drink mix
Accessory packet
Spoon

### MENU 2

Beef Stew
Granola bar
Chocolate covered cookie
Caramels
Cocoa
Accessory packet
Spoon

### MENU 3

Escalloped Potatos and Pork
Cornflake and Rice Bar
Fig Bar
Chocolate bar w/Toffee (2 oz)
Apple cider drink mix
Accessory packet
Spoon

### MENU 4

Chicken ala King
Cornflake bar
Chocolate covered cookie
Starch Jellies (Chuckles)
Orange beverage
Accessory packet
Spoon

### MENU 5

Chicken and Rice
Granola bar
Chocolate covered brownie
Starch Jellies (Chuckles)
Lemon tea (2 pks)
Accessory packet
Spoon

### MENU 6

Spag/w Meat Sauce
Cornflake and Rice bar
Oatmeal cookie bar
Tootsie roll (4 pks)
Beverage base (MRE)
Accessory packet
Spoon

### MENU 7

Chili con Carne
Granola bar
Chocolate covered brownie
Charms
Orange beverage
Accessory packet
Spoon

### MENU 8

Beef with Rice
Cornflake bar
Fig bar
M&Ms
Lemon tea (2 pks)
Accessory packet
Spoon

Accessory packet: Coffee, creamer, sugar, salt, gum, matches, toilet paper (2 pks)

**Table 2.1. LLRP Menu Items**

| SCENARIO | EQUIPMENT | UNIT PRICE |
| --- | --- | --- |
| MANUAL | 2 Totes | $70 |
| | 1 Table and Stool | $300 |
| | 8 Bins | $15 |
| | 1 Table Extension | $80 |
| | 3 sealers | $2500 |
| MANUAL ADVANCED | 6 Flow Racks | $300 |
| | 6 Stools | $70 |
| | 3 sealers | $2500 |
| | 1 40' conveyor | $25,740 |
| SEMI-AUTOMATIC | 1 Dispensing Machine | $250,000 |
| | 6 Flow Racks | $300 |
| | 6 Stools | $70 |
| | 3 sealers | $2500 |
| MANUAL CRAMTD | 1 Form/Fill/Seal Machine | $175,000 |
| | LLRP formset | $30,000 |
| | 3 Flow Racks | $300 |
| | 3 stools | $70 |
| ADVANCED CRAMTD | 1 Form/Fill/Seal Machine | $175,000 |
| | LLRP formset | $30,000 |
| | 1 Robot w/vision | $125,000 |
| | gripper/integration | $55,000 |
| | 2 Dispensing Machines | $250,000 |

Table 4.1. INSTRUMENTED PRODUCTION MODULES (IPMs)

*SCENARIO 1: MANUAL BENCH ASSEMBLY*

Labor Rate ▪ \$5/hr, Daily Production Rate ▪ 5056 LLRPs/8 hr

| Annual Demand | Production Hours | # of shifts | # of workers | Labor Cost | Equipment Cost | Packaging Mat. Cost | ATC | Cost/LLRP |
|---|---|---|---|---|---|---|---|---|
| 1 mil | 1582 | 1 | 6 assemblers<br>2 suppliers<br>3 sealer operators<br>11/shift | \$87,010 | \$1751 | \$110,000 | \$119,957 | \$.12 |
| 5 mil | 3956 | 2 | 12 assemblers<br>4 suppliers<br>6 sealer operators<br>22/shift | \$435,160 | \$2344 | \$550,000 | \$593,440 | \$.12 |
| 10 mil | 5274 | 3 | 18 assemblers<br>6 suppliers<br>9 sealer operators<br>33/shift | \$870,210 | \$2937 | \$1,100,000 | \$1,185,063 | \$.12 |

Note: Equipment Cost is given in Equivalent Uniform Annual Cost

Table 4.2. Scenario 1 Cost Analysis

*SCENARIO 2: MANUAL ADVANCED ASSEMBLY*

Labor Rate ▪ \$5/hr , Daily Production Rate ▪ 5712 LLRPs/8 hr

| Annual Demand | Production Hours | # of shifts | # of workers | Labor Cost | Equipment Cost | Packaging Mat. Cost | ATC | Cost/ LLRP |
|---|---|---|---|---|---|---|---|---|
| 1 mil | 1401 | 1 | 6 assemblers<br>2 suppliers<br>3 sealer operators<br>11/shift | \$77,056 | \$5475 | \$110,000 | \$117,708 | \$.12 |
| 5 mil | 3502 (2 lines) | 2 | 12 assemblers<br>4 suppliers<br>6 sealer operators<br>22/shift | \$385,220 | \$10,950 | \$550,000 | \$572,082 | \$.11 |
| 10 mil | 4669 (3 lines) | 3 | 18 assemblers<br>6 suppliers<br>9 sealer operators<br>33/shift | \$770,352 | \$16,425 | \$1,100,000 | \$1,138,633 | \$.11 |

Note: Equipment Cost is given in Equivalent Uniform Annual Cost

Table 4.3. Scenario 2 Cost Analysis

## *SCENARIO 4: MANUAL CRAMTD LLRP ASSEMBLY*

**Labor Rate = \$5/hr, Daily Production Rate = 5712 LLRPs/8 hr**

| Annual Demand | Production Hours | # of shifts | # of workers | Labor Cost | Equipment Cost | Packaging Mat. Cost | ATC | Cost/ LLRP |
|---|---|---|---|---|---|---|---|---|
| 1 mil | 1401 | 1 | 3 assemblers<br>1 supplier<br>4/shift | \$28,020 | \$31,826 | \$90,000 | \$102,638 | \$.10 |
| 5 mil | 3502 (2 lines) | 2 | 6 assemblers<br>2 suppliers<br>8/shift | \$140,080 | \$63,652 | \$450,000 | \$417,700 | \$.08 |
| 10 mil | 4669 (3 lines) | 3 | 9 assemblers<br>3 suppliers<br>12/shift | \$280,128 | \$95,478 | \$900,000 | \$803,555 | \$.08 |

Note: Equipment Cost is given in Equivalent Uniform Annual Cost

Table 4.4. Scenario 4 Cost Analysis

## *Preliminary Assembly Cost Summary*

| SCENARIO | ANNUAL DEMAND | COST/LLRP @ $5/hr | COST/LLRP @ $8/hr |
|---|---|---|---|
| Manual | 1 mil | $.12 | $.15 |
| | 5 mil | $.12 | $.15 |
| | 10 mil | $.12 | $.15 |
| Manual Advanced | 1 mil | $.12 | $.14 |
| | 5 mil | $.11 | $.14 |
| | 10 mil | $.11 | $.14 |
| Manual CRAMTD | 1 mil | $.10 | $.11 |
| | 5 mil | $.08 | $.09 |
| | 10 mil | $.08 | $.09 |

Table 4.5. Labor Rate Sensitivity

## SUMMARY OF SCENARIO ADVANTAGES/DISADVANTAGES

| SCENARIO | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| MANUAL | flexibility<br>ability to respond to demand changes | separate sealing operations<br>labor intensive |
| MANUAL ADVANCED | continuous material flow<br>higher production rate than manual | separate sealing operations<br>inflexible |
| SEMI-AUTOMATIC | computer control of dispensing<br>continuous material flow | mechanical unreliability<br>highly capital intensive |
| MANUAL CRAMTD | lower labor requirement<br>integrated filling/sealing ops.<br>ability to respond to demand changes<br>flexibility to produce MREs | capital cost |
| ADVANCED CRAMTD | minimal labor requirement<br>high production rate<br>integrated filling/sealing ops. | highly capital intensive<br>technical difficulties |

Table 4.6. Scenario Advantages/Disadvantages

## Figure 4.1. Scenario 1: Manual Bench Assembly

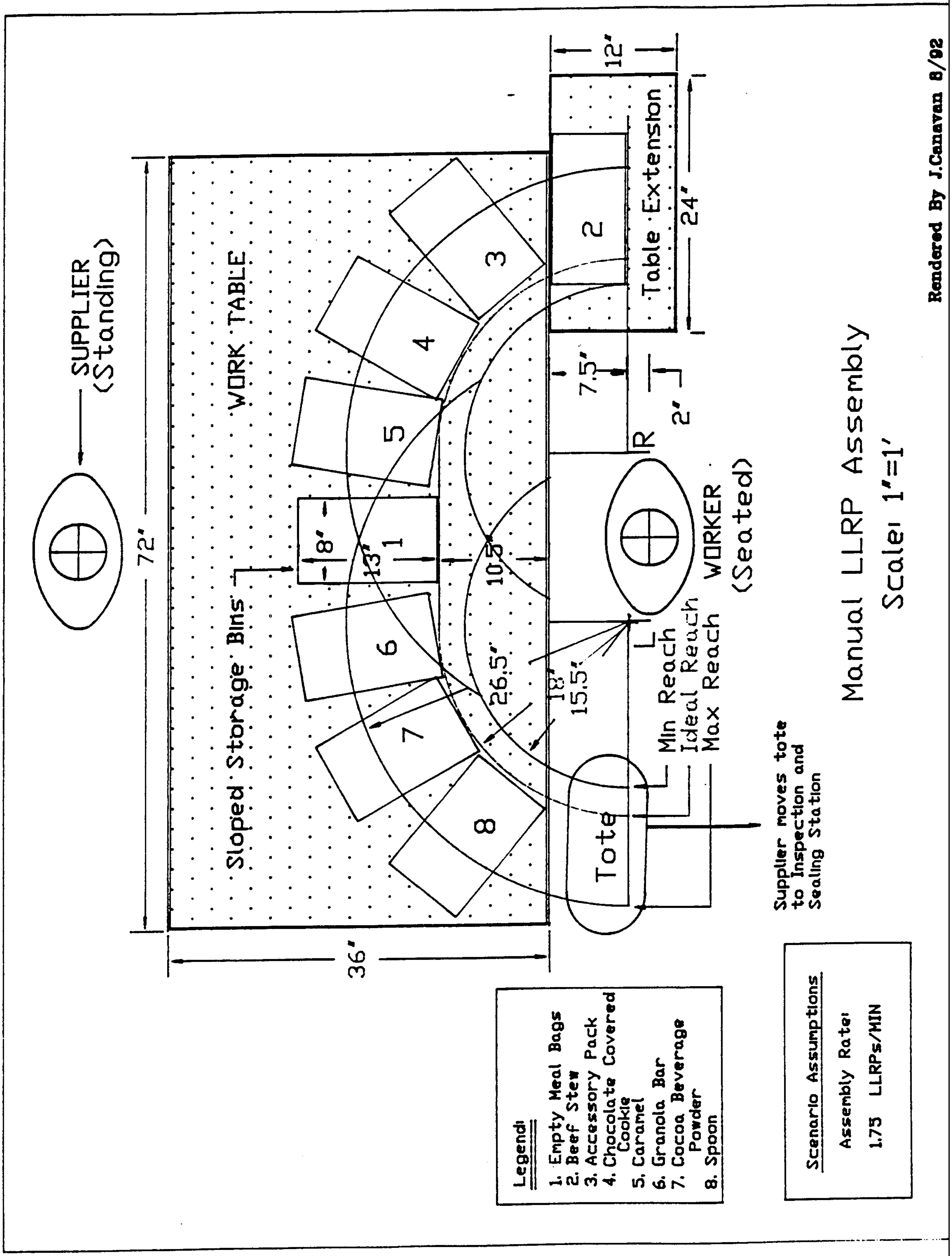


**Figure 4.2. Scenario 2: Manual Advanced Assembly**

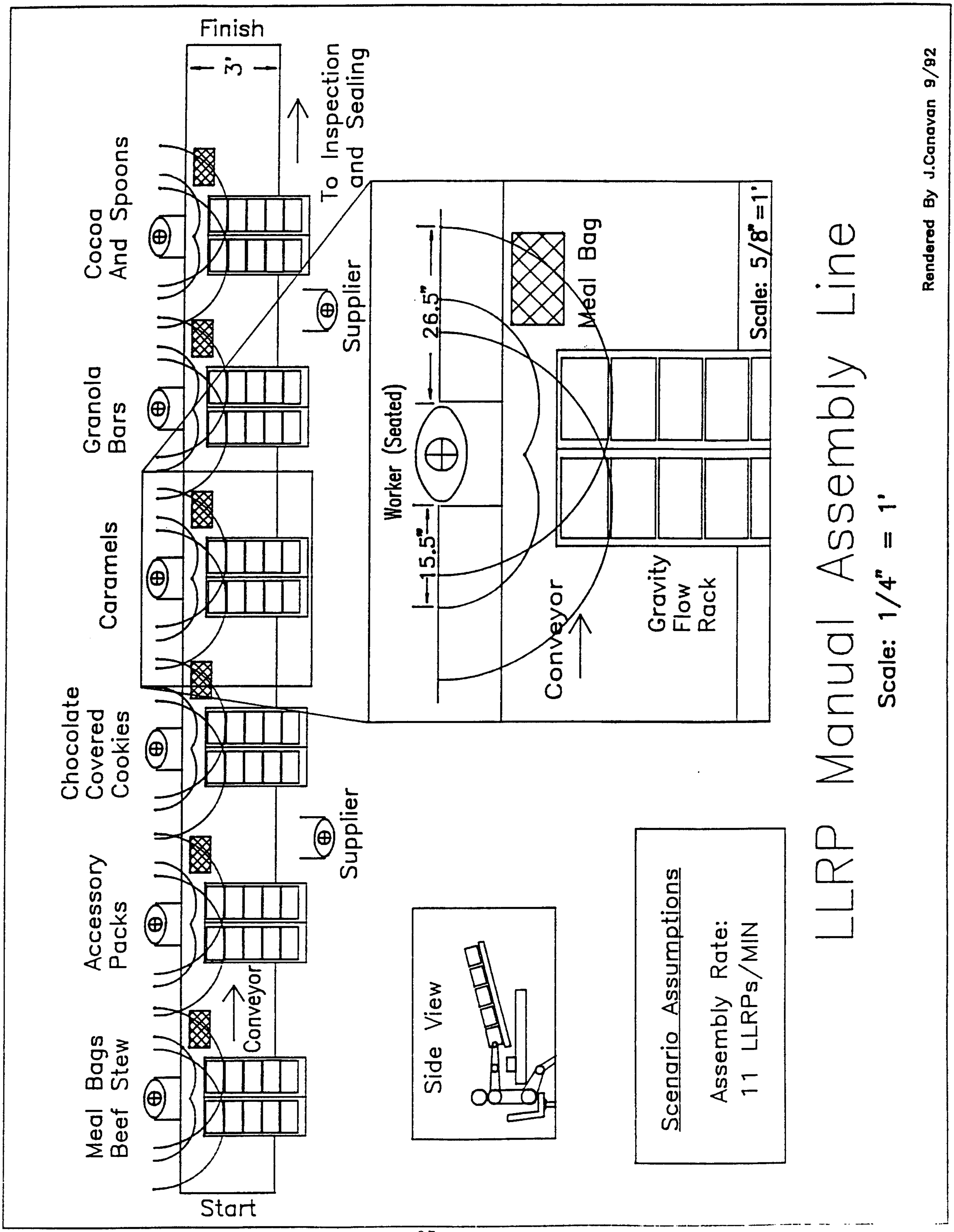


**Figure 4.3. Scenario 3: Semi-Automatic Assembly**

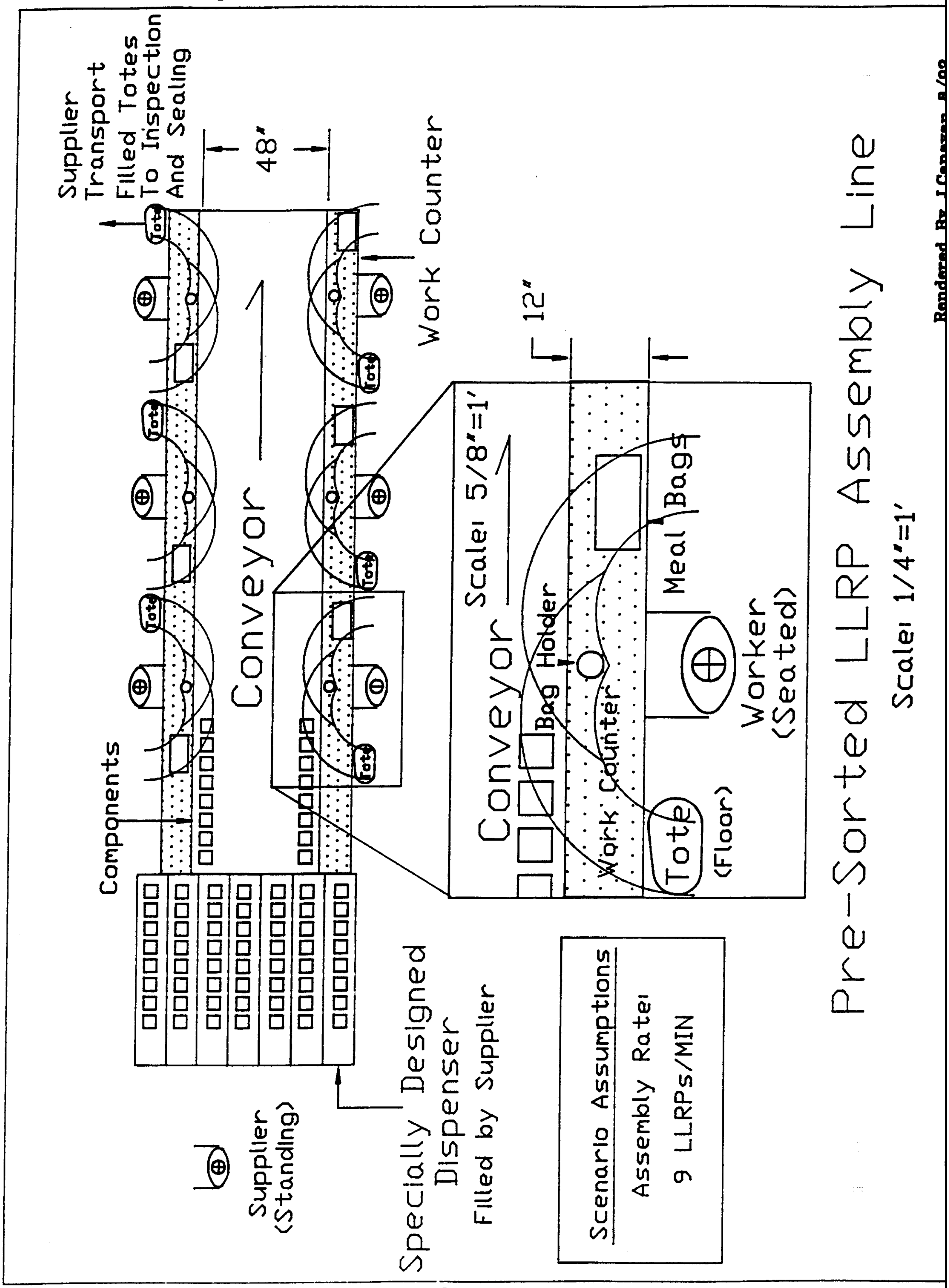
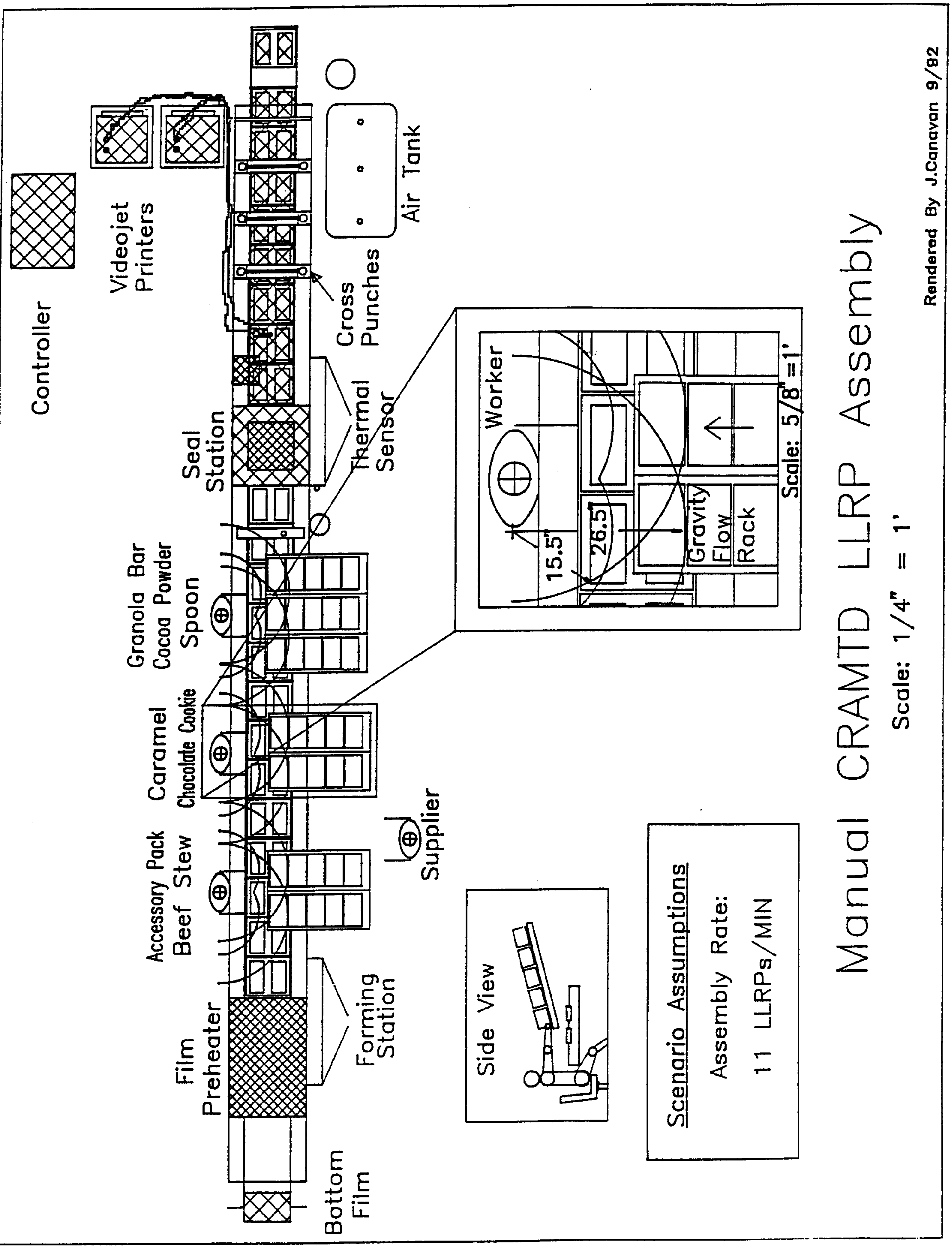


**Figure 4.4. Scenario 4: Manual CRAMTD LLRP Assembly**



## Figure 4.5. Scenario 5: Advanced CRAMTD LLRP Assembly

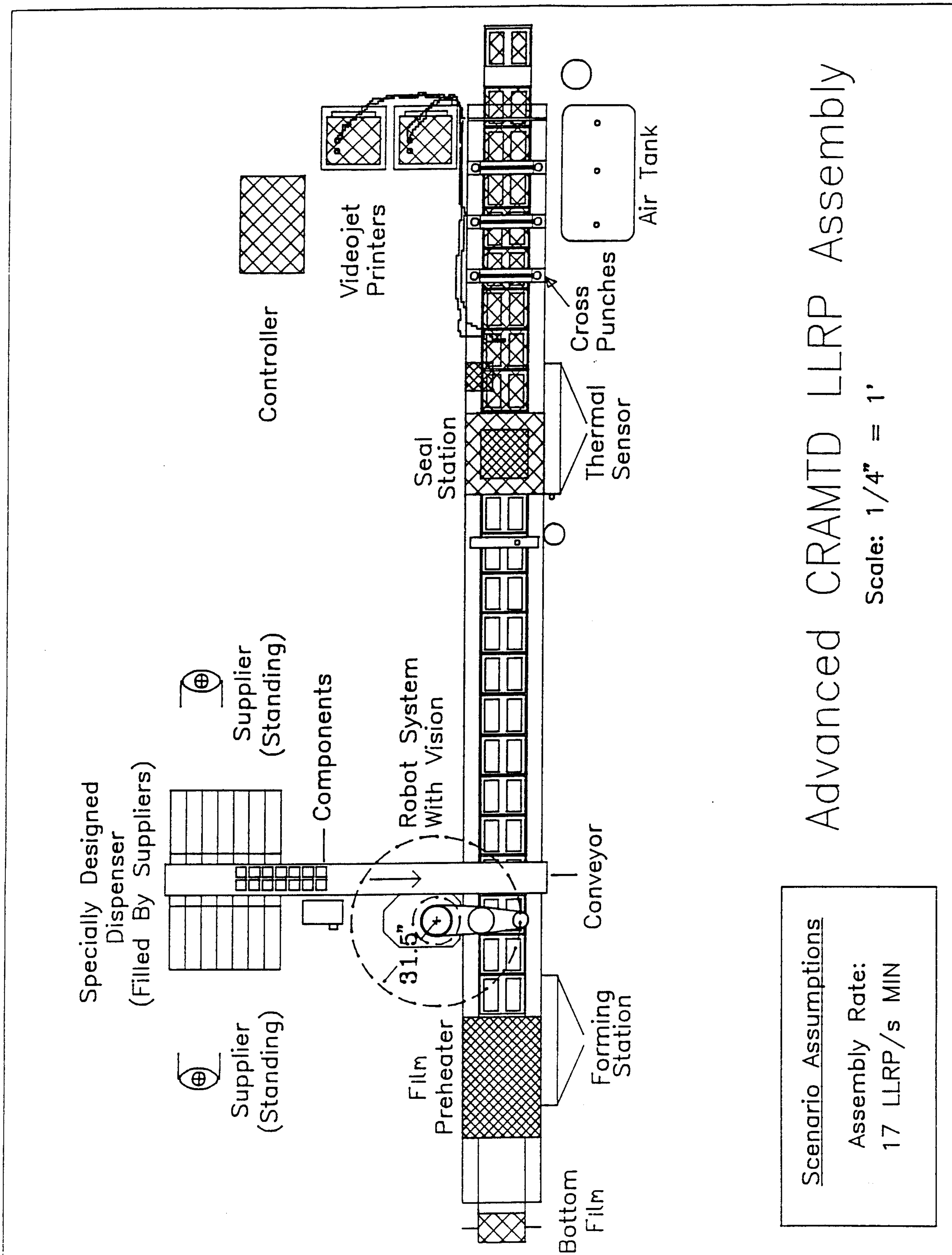
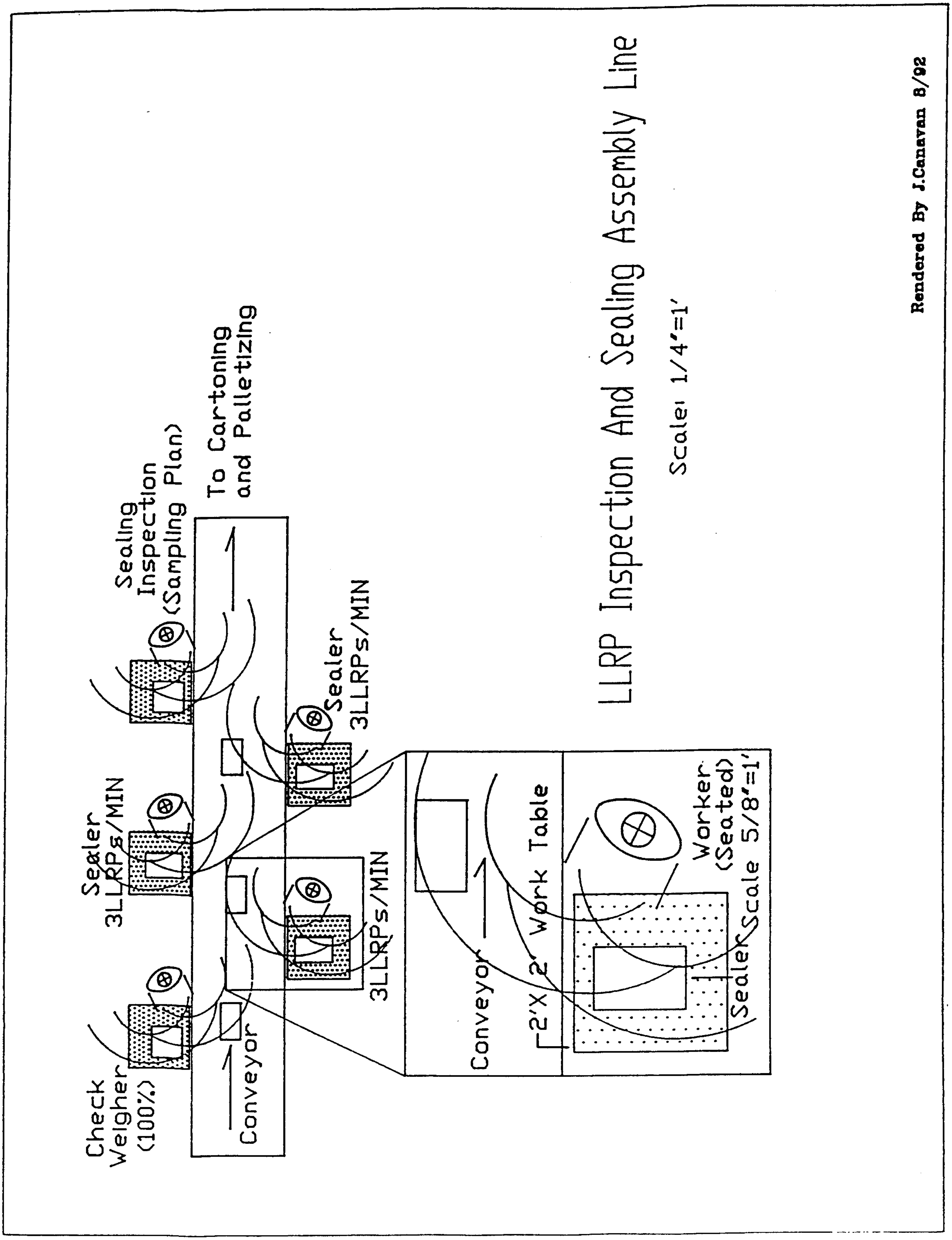


Figure 4.6. Inspection and Sealing Line for Scenarios 1-3



# COMBAT RATION ADVANCED MANUFACTURING TECHNOLOGY DEMONSTRATION (CRAMTD)

## Evaluation of Sizes and Shapes for Long Life Combat Rations

**Technical Working Paper (TWP) 66**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# 1.0 INTRODUCTION

The military is interested in early fielding of the Long Life Ration Packet (LLRP) to meet unique Service requirements. Many of the individual food items were previously used in other rations; however, the sizes and shapes of the items for the previous rations have not been modified to optimize the bulk packing density for this ration. While the DPSC and CRAMTD emphasis is more on processing than on configuration or size, in the case of LRP-II the sizes and shapes may affect the configuration of tooling. Therefore, there is a need to review the component sizes, shapes, and even packaging materials to optimize the cubic volume of the finished ration to be carried by the user, or to be placed in storage.

In the next section a brief historical perspective of freeze drying operations is provided. This survey also includes a listing of the proposed menu items for LLRPs. Packaging issues are addressed in Section 3 and Recommendations in Section 4.

# 2.0 LITERATURE SURVEY

Dalgleish (1990) provides detailed discussions of both the evolution and technical procedures of freeze drying operations. After World War II there was a realization by the various military organizations that there was a compelling need to establish large-scale food production systems to supply military personnel. The technical advantages of freeze drying are that it is performed at relatively low temperatures and there is no shrinkage as with hot-air drying, so the light and porous components retain their shape and dimensions. Since these individual components can be easily reconstituted to a close resemblance to the original in color, texture, odor, and flavor, freeze drying of foodstuffs was considered to be an attractive technology.

In 1948 the Commonwealth Advisory Committee on Defense Science (CACDS) in England realized the importance of continuing to research alternative food production systems. Dehydration was considered as a promising food process since it had made significant contributions during the war; however, its limitations were also becoming apparent. Researchers in Denmark had developed a novel vacuum-drying process that was utilized in Norway after the war for the production of dried fish. After examining this facility, representatives of the United Kingdom initiated a plan to construct an experimental factory in Aberdeen, Scotland. With the Ministry of Food spearheading the project, the plant was constructed, and it operated for approximately 10 years. The plant was closed in 1961 but not before developing an Accelerated Freeze Drying (AFD) Process. With the AFD process, products 15 mm in thickness could be dried in less than an 8-hour shift as opposed to 48 hours using earlier freeze drying methods. The Aberdeen project experimented with the dehydration of many individual components and created a number of complex recipes for soups, sauces, steaks, fish, etc..

Due to political and socio-economic pressures, the Ministry of Food abandoned the Aberdeen project and private firms began to investigate freeze drying operations. Food companies in Denmark, Ireland, Italy and Germany designed and developed freeze drying plants worldwide. Some engineering modifications to the basic processing equipment for vapor disposal also emerged. Some of the leading companies in this era were Atlas, Vickers Armstrong, Leybold, and Erin Foods. Erin Foods opened some freeze drying factories in America in the mid-1960s.

During the 1970s new techniques emerged among commercial freeze drying companies. During the early days of freeze drying it was difficult to determine when a product reached the stage of being fully and properly processed, so allowances of up to an extra 100% cabinet time were typically permitted. Numerous mechanical devices and processing techniques for controlled heating were soon developed.

Freeze drying became very popular in the 1980s with growing consumer interest in personal convenience of food preparation. Also, the increased popularity of camping and hiking has led to a renewed interest in freeze-dried foods. Astronauts have been trained to use salivation as a means of adequately preparing a number of substances for consumption (Dalgleish, 1990). Freeze drying offers quality and variety in over 400 different food items (Duxbury, 1988). In the United States, Oregon Freeze Dry Foods Inc. has supplied U.S. agencies for the past 25 years with many diverse products including long range patrol rations for the U.S. Marines. As Dalgleish (1990) concludes "the substantive reasons for freeze drying foodstuffs remain investment in (a) personal convenience of stored true wealth, (b) rapid realizability of staple necessities, and (c) security from supra-national calamity" (p.218).

## 2.1 Menu Items

Table 2.1 displays a list of 8 menu items under consideration which was provided by the Natick Research, Development & Engineering Center (NATICK). Note that LLRP and LRP-II are used interchangeably in this report.

Each LLRP consists of 7 individual components which are sealed with aluminum foil. The individual components are then placed inside a polyethylene meal bag with a density of 0.910 to 0.929 g/cm$^3$. The inside width of the bag is to be not less than 7 inches and not more tha 7-5/8 inches and the inside length is to be 11-7/8 inches (+ or - 1/8 inch). The 7 components are to be "arranged in such manner as to occupy the minimum amount of space while maintaining a flat configuration" (MILSPEC "Assembly of Long Life Ration Packet", p.8). Excess air is to be expelled prior to sealing with heat to allow packing of the meal bags. Sixteen filled and sealed meal bags will then be placed into a shipping container (cardboard carton). It is estimated, by NATICK, that LRP-II has a shelf life of approximately 10 years.

# LONG LIFE RATION PACKET 1991 ASSEMBLY

AS OF: 10-Feb-92

MENU 1

Chicken Stew
Cornflake bar
Oatmeal cookie bar
Tootsie roll (4 pks)
Apple cider drink mix
Accessory packet
Spoon

MENU 2

Beef Stew
Granola bar
Chocolate covered cookie
Caramels
Cocoa
Accessory packet
Spoon

MENU 3

Escalloped Potatos and Pork
Cornflake and Rice Bar
Fig Bar
Chocolate bar w/Toffee (2 oz)
Apple cider drink mix
Accessory packet
Spoon

MENU 4

Chicken ala King
Cornflake bar
Chocolate covered cookie
Starch Jellies (Chuckles)
Orange beverage
Accessory packet
Spoon

MENU 5

Chicken and Rice
Granola bar
Chocolate covered brownie
Starch Jellies (Chuckles)
Lemon tea (2 pks)
Accessory packet
Spoon

MENU 6

Spag/w Meat Sauce
Cornflake and Rice bar
Oatmeal cookie bar
Tootsie roll (4 pks)
Beverage base (MRE)
Accessory packet
Spoon

MENU 7

Chili con Carne
Granola bar
Chocolate covered brownie
Charms
Orange beverage
Accessory packet
Spoon

MENU 8

Beef with Rice
Cornflake bar
Fig bar
M&Ms
Lemon tea (2 pks)
Accessory packet
Spoon

Accessory packet: Coffee, creamer, sugar, salt, gum,
matches, toilet paper (2 pks)

Table 2.1. LLRP Menu Items

## 3.0 SIZES AND SHAPES OF COMPONENTS AND PACKET

This section presents the study on the optimal sizes and shapes of the components and ration packets. Based upon initial literature survey and discussions, the research has focused on the following steps:

1. Review of the current LRP packages.
2. Identify key factors to be considered for reducing the overall package volume.
3. Search for feasible ways to reduce the volume through physical simulations for sample meal bags/trays.
4. Provide suggestions for the sizes and shapes to achieve the optimal package volume.

In the first step to analyze the current packages, we used a sample packet made by CINPAC sent to us by NATICK in July, 1992. Since it has not been possible to visit any of the production sites to collect information regarding the industrial packaging processes, we have relied on the simulation models and scenarios developed by Prof. Luxhoj reported in CRAMTD Technical Working Paper TWP #65 to understand the packaging processes.

The second step identified the major factors affecting the overall volume of the LRP package. Through step 1 and using the basic concept from optimization theory, we concluded that the study should focus on the following two factors: (1) the sequence of packing the components into each meal bag/tray and the corresponding locations of the components, and (2) the shapes of individual components for a given sequence of packing.

For the third step, our study showed that it would be quite difficult to consider the optimal sizes and shapes of the components without knowing the sequence of packing them into the meal bag. Therefore, we studied the packing sequence first, and then the optimal shapes. Two different packages were assumed: Meal bag as is used in the CINPAC sample, and tray which is considered as an alternative in a form-fill-seal line. For meal bag, we ran some physical simulations to figure out the best sequence of packing components. A simple sequencing rule was identified for packing the meal bag. We also ran similar tests for tray assuming that horizontal filling and sealing would be performed on a form-fill-seal line. A rule for sequencing components for the tray is developed after simulating all 8 menu items. We also determined proper sizes of the tray which can accommodate any menu.

Finally, we studied how one could possibly achieve minimum volume for a sample menu. Our focus has been on finding the best shapes of the "major" components (e.g., entree packet) that affect the "height" of the meal bag/tray (i.e., make the bag/tray flat by re-shaping the components). Recommendations are made at the end.

### 3.1 Review of the current LRP packages

There are 8 different menus for LRP packages. Each LRP meal bag consists of 7 components. Each component is sealed with aluminum foil, and placed inside a meal bag made from polyethylene tubing. The bag is then sealed and placed into a shipping container (cardboard carton). Each carton contains 16 meal bags, two for each menu.

The dimensions of the shipping carton and the way in which 16 meal bags are packed are shown in Figure 3.1. The sample we used in the diagram was packaged by CINPAC, Ohio. The dimensional definitions of a meal bag to be used in this report are given in Figure 3.2. The current packaging layout and sizes of the bags meet the military specifications draft provided by NATICK. A summary of the specifications for the meal bag and some components are provided in Table 3.1.

Figure 3.1 Shape and sizes of the existing package

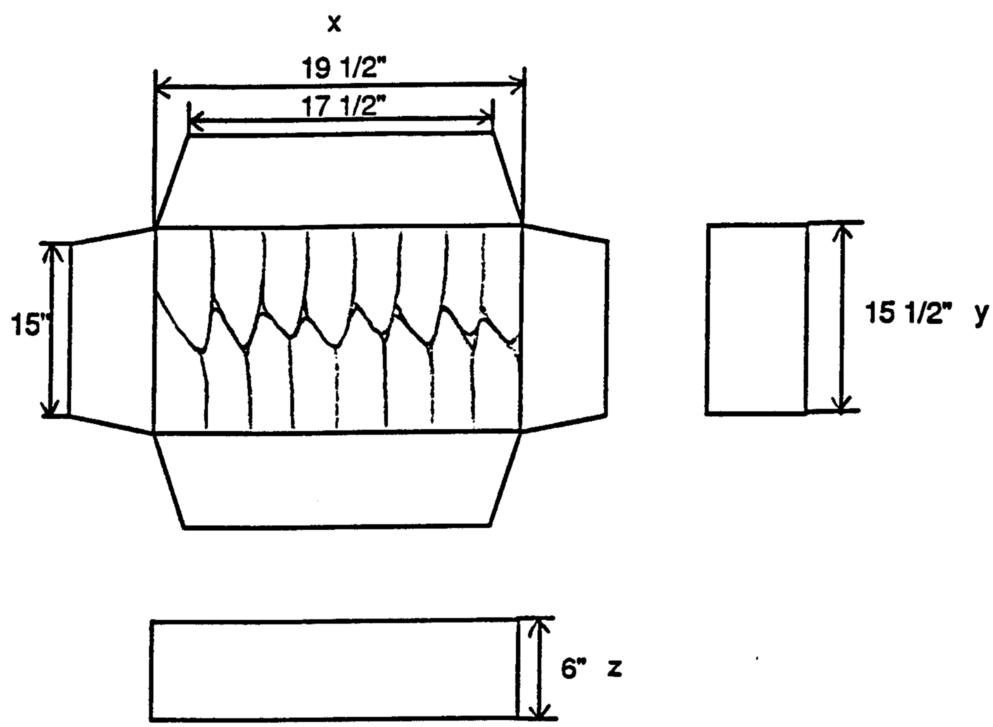



Figure 3.2 Definitions of the dimensions for meal bag

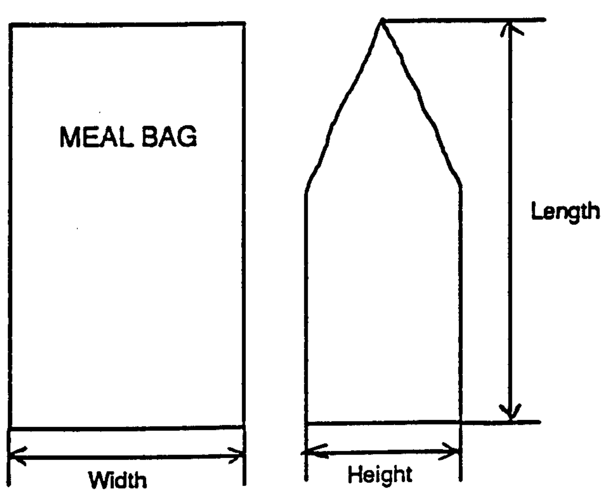


Table 3.1 Military specifications for shipping carton, meal bag, and some components

| Items | Length | Width | Height | Remarks |
| --- | --- | --- | --- | --- |
| Carton | 191/2 | 151/2 | 6 | Inside |
| Meal Bag | 11 7/8 (±1/8) | 7 to 7 5/8 | | Inside |
| Accessory Packet Preformed | 5 5/8 to 6 | 3 5/8 to 4 | | Inside |
| Accessory Packet Form-Fill-Seal | 6 (±1/16) | 51/2 (±1/16) | | Outside |
| Entree Mixing bag type 1 | 8 (±1/8) | 51/2 (±1/8) | 31/2 (±1/8) | Inside |
| Entree Mixing bag type 2 | 9 | 8 | | Inside |
| Entree Pouch | 9 (±1/8) | 6 (±1/8) | | Inside |
| Apple Cider Mix | 4 3/4 (±1/8) | 3 6/8 (±1/8) | | |
| Candy Packet Preformed | 4 3/4 to 7 | 1 1/2 to 3 1/4 | | Inside |
| Candy Packet Form-Fill-Seal | 7 1/4 (±1/16) | 5 1/4 (±1/16) | | Inside |
| Tea Mix Pouch | 3 7/8 (±1/8) | 2 1/8 (±1/8) | | Inside |
| Fig Bar Preformed pouch | 5 1/4 (±1/16) | 2 3/4 (±1/16) | | Inside |
| Fig Bar Form-Fill-Seal | 5 1/2 (±1/16) | 5 1/2 (±1/16) | | Outside |
| Oatmeal Cookie Bar Preformed | 5 3/4 (±1/8) | 2 3/4 (±1/8) | | Inside |
| Oatmeal Cookie Bar Form-Fill-Seal | 6 3/8 max | 3 1/4 max | | Outside |
| Orange Bevrg. Base | 4 3/4 (±1/8) | 3 7/8 (±1/8) | | Inside |

### 3.2 Major factors for minimizing the overall volume

Through careful examinations of the existing meal bags, we identified the followings:

(1) The overall volume (i.e., volume of the shipping carton) can be significantly reduced by reducing the height of the individual meal bag. In other words, a flatter bag would save the total package volume. See Figure 3.2 for the definition of the height for a meal bag.

(2) Depending upon the sequence of packing and the locations of individual components, the height of each meal bag can be varied significantly for the same sizes and shapes of the components.

(3) It is quite difficult to determine the optimal shapes and sizes of the components without the packing sequence and the corresponding locations of the components known a priori. Once the sequence and the location of each component inside the meal bag/tray are given, it may be possible to determine the best shapes and sizes.

We now discuss each of the above conclusions in more detail.

(1) Our problem can be described as a conceptual optimization problem as follows:

Let $x$ = length of the shipping carton,
$y$ = width of the carton,
$z$ = depth of the carton, (see also Figure 3.1 for these definitions)

then, our problem is:

Minimize $x * y * z$ (i.e., volume of the carton)
subject to
(1) constraint on x, y, and z for satisfying the minimum volume required for the individual meal bag
(2) relationship between y and the length of overlapping between two opposing bags inside the box

From our preliminary computational effort, it has not been possible to get any "applicable" solutions for the problem due to the fact that the optimal solution cannot precisely consider the shapes and sizes of the individual meal bags. But, such attempts and the above model taught us that if one is allowed to reduce only one side of the box it would be better to consider the length (longest side which is 19.5" in Figure 3.1) first. Analysis of the current package also suggested that there is more room for possible reduction of the overall volume by reducing the length than the width of the box. In other words, reducing the height of the individual meal bag would be an important factor. Let us show how much savings would be possible using a numerical example.

From the size of the current carton, the limit on the average height of each meal bag is approximately 2.4 inches. Suppose we could reduce it by 0.1 inch down to 2.3 inches. The saving to be obtained in the total volume is almost 4% over the current volume. A 1/4 inch reduction of the individual bag height can result in 10% reduction of the total volume. Thus, we decided to focus on the methods/designs to achieve the "most flat" or evenly-packed meal bag/tray.

(2) We then proceeded to examine pairs of identical menus, comparing the way they were packed and the height differences. Notable differences in the height were found for all the pairs, for example, 2 3/4 and 2 1/2 inches for two Beef Stew bags. We opened up two meal bags and compared the locations of the components, which were quite different between the bags. We tried different sequences of packing the components and found that the resulting height depends upon the sequence of packing and the corresponding locations of the components. Therefore, we investigate this problem further in the following section using the Beef Stew meal bag as a demo case.

(3) We have examined some 3-dimensional volume optimization models using the basic Operations Research-type methods, but it has not been possible to define the problem without knowing the sequence of packing and locations of the components. Even with such information, it seemed hardly possible to formulate an optimization model and solve for an optimal solution. (For a 2-dimensional problem, there exists some algorithms, but not for a 3-dimensional problem.) Therefore, we decided to apply a heuristic approach (trying to find a "good" solution, not necessarily an optimum, by applying a systematic procedure) to find the best shape for each component once the packing sequence and the locations are determined.

### 3.3 Study of the packing sequences

Assuming that we are using the same sizes and shapes of the components found in the sample bags, we consider the packing sequences for both meal bag and tray in the following sections.

**Meal bag**

In this section, we first examine the packing sequence of the beef stew menu to obtain the flattest shape of the meal bag. After a number of manual simulations testing different packing sequences, the following sequence provided the best shape:

| Sequence | Component |
|---|---|
| 1 | Beef Stew Packet |
| 2 | Accessory Packet |
| 3 | Chocolate Covered Cookie |
| 4 | Caramel |
| 5 | Granola Bar |
| 6 | Cocoa Beverage Powder |
| 7 | Spoon |

Interestingly, the above sequence is identical to the sequence assumed in Dr. Luxhoj's simulation models (Technical Working Paper, TWP #65). The sequence is in fact following a simple rule: Bigger components first. The rationale behind it is that the overall volume can be reduced by packing with bigger components first and then filling the gap with smaller ones. Our physical simulation suggests that mixing the sequences 3, 4 and 5 (i.e., candy bars in similar shapes) would not significantly change the resulting height of the meal bag.

We also tested the remaining menus to check the feasibility of the above rule, and found that the rule worked for the other menus as well. Thus, a generic rule for sequencing the components is:

| Sequence | Component |
|---|---|
| 1 | Entree Packet |
| 2 | Accessory Packet |
| 3, 4, 5 | Candy, Cookie and/or Caramel bars |
| 6 | Beverage Mix |
| 7 | Spoon |

**Tray**

Assuming a tray is used on a form-fill-seal line as designed in Dr. Luxhoj's work, we run similar physical simulations. However, in this part, we have an additional dimension to the problem which is the unknown size of the tray. It turned out to be difficult to determine the size of the tray and the packing sequence simultaneously. Thus, we start with a reasonable size of the tray and try different packing sequences, and then iteratively repeat the cycle with a reduced size of the tray until no reduction of the tray size is possible.

We test all 8 menus assuming a common tray sizes. The resulting sequence of packing the components in the tray for menu #2 is as follows. The sizes of the tray are shown in Figure 3.3.

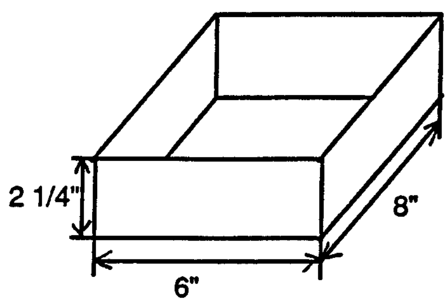
| Sequence | Component |
|---|---|
| 1 | Accessory Packet |
| 2 | Beef Stew |
| 3 | Chocolate Covered Cookie |
| 4 | Granola Bar |
| 5 | Beverage |
| 6 | Caramels |
| 7 | Spoon |

The above sequence is somewhat different from that of the previous section. Because we assumed that the packing of individual components is done by "horizontal filling", it is not necessarily best to put a bigger component first in the tray. For example, Accessory Packet goes in first to fit the Entree packet better at the bottom. It is also noted that some careful "orienting" and "placing" of each component are necessary to minimize the volume. Without such a careful orienting, we anticipate that using a tray would increase the total volume. However, if at the sealing station air is sucked out of the tray and sealed, it would of course reduce the volume. Even though such vacuuming is not enforced in any part of the current military specs, it may be worthwhile to consider it as an option for the CRAMTD line.

By simulating the remaining 7 menus, we identify the following common sequencing rule and the corresponding locations of the individual components:

| Sequence | Component | Location |
|---|---|---|
| 1 | Accessory Packet | flat on one side of the bottom of the tray |
| 2 | Entree Packet | flat on the other side of the bottom |
| 3 & 4 | Two short cookie/candy bars | next to Entree & on top of Accessory |
| 5 | Beverage | flat on top of the bars |
| 6 | Long candy bar | fit the longer side of the tray |
| 7 | Spoon | next to the long candy bar on the long side |

Figure 3.3 Tray for the existing components




The actual shape of the tray may not be exactly rectangular on the side depending upon the shape of the forming die. However, slightly smaller-sized bottom (e.g., less than 1/8" reduction on each side) resulting from some curved shape of the tray may affect neither the above packing sequence nor the total volume significantly.

The volume of the shipping carton may be approximated without considering the seal allowances of the trays. 16 trays are assumed in a box, and the resulting overall volume of the box becomes 1728 $in^3$. Considering the volume of the current carton for the meal bag is 1813.5 $in^3$, <u>there is a slight reduction (4.7%) in the total volume using the above tray</u>. It is believed that the actual total volume of the carton with minimal seal allowance of the tray will be close to the estimated value, since the tray may have some flexibility.

### 3.4 Study of the optimal sizes

In the previous section, we assumed that the same components found in the sample meal bag were used. Through the physical simulations, we noted that a substantial saving would be possible by simply reducing the "seal allowances" without changing the net shape of each component. Thus, in this section, we study the optimal sequence of packing the components into the tray while changing the shapes of the components (basically making each component more compact by reducing the seal allowances). To demonstrate how such an optimization can be performed, we use one sample menu, Beef Stew pack. Again, the tray size is determined by iteratively shrinking it after each cycle of manual packing for different sequences as in the previous section.

The resulting best sequence of packing the "compacted" components is given below. The final size of the tray is shown in Figure 3.4.

| Sequence | Components | Location |
|---|---|---|
| 1 | Cocoa Beverage | flat on to one side of the bottom of the tray |
| 2 | Accessory Packet | flat on to the other side of the bottom |
| 3 | Beef Stew Packet | on top of the accessory packet |
| 4 | Cookie Bar | its long edge placed opposite to the stew |
| 5 | Granola Bar | its long edge placed between stew & cookie bar |
| 6 | Caramel Bar | its long edge placed along the length of the tray |
| 7 | Spoon | between caramel bar & stew |

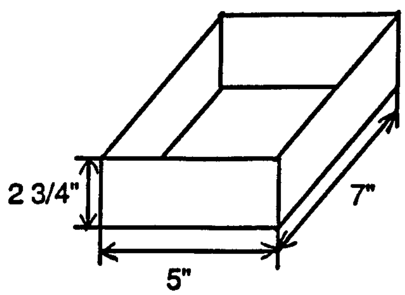
To achieve the minimum volume, specific location and layout of each component is extremely important as shown above. Furthermore, we assumed the followings:

1. All the seal allowances are minimized while retaining the original net shapes of the components as found in the sample bag. (i.e., military specification for individual component packet is ignored.)

2. Any seal allowance is pressed flush against the side of the component so as not to occupy extra volume.

The above assumptions ignored any physical packaging processes to be used due to the limited information of the commercial or CRAMTD packaging equipment. The main goal of the study in this section is to find the best possible shapes and sizes of the components and the tray, even though they may not be feasible production-wise. However, such study may provide a benchmark for the feasible shapes and sizes. A designer may use such information to find out how far his/her design is off from the "theoretically achievable" minimum.

Fig 3.4 Optimal size of tray with "compacted" components for a sample menu




As depicted in the above figure, the tray sizes have been reduced significantly (one inch reduction on each of the two long sides by adding 1/2" to the short side). The estimated volume of the carton is now 1540 $in^3$, 15.4% reduction over the previous volume of the shipping carton.

An interesting question at this point is: How good is the above result? One way to answer such a question in Industrial Engineering arena is comparing the result to the theoretical "lower bound" which is "the minimum which is never possible to beat". We thus calculate such a lower bound for the volume of the carton using the net shapes of the components. The bound obtained is 1120 $in^3$, which proves that the best result we have is indeed 37.5% above the lower bound. The earlier result for the tray was 62.5% bigger than the lower bound. This may indicate that for a designer of the tray and the carton the target volume to shoot for must be within 40-60% above the lower bound, or 1560-1800 $in^3$.

We now proceed to suggest the possible specifications for the sizes of the components. The suggested specifications were used for the above simulations, and conjectured to be manufacturable by the component vendors. The new specs are given in Table 3.2.

Table 3.2 Suggested specifications for the components in Menu #2

| Items | Length | Width | Height | Remarks |
|---|---|---|---|---|
| Meal Tray | 7 | 5 | 2 3/4 | Inside |
| Accessory Packet (assumed preformed) | 51/2 | 3 1/2 | 7/8 max | Inside |
| Entree Mixing bag | 5 1/2 | 3 1/2 | 8 | Inside |
| Entree Pouch | 7 1/2 | 6 | | Inside |
| Candy Overwrap | 4 3/4 | 1 1/2 | | Inside |
| Cookie Bar Preformed | 3 1/2 | 2 1/2 | | Inside |
| Granola Bar | 3 3/4 | 1 3/4 | | Inside |
| Cocoa Powder Preformed | 4 1/4 | 3 1/4 | | Inside |

# 4.0 SUMMARY AND RECOMMENDATIONS

As a part of CRAMTD STP #9 Phase I, this study of the shapes and sizes of the components in the LRP packet has focused on the followings: (1) Identifying the key factors for reducing the packaging volume, (2) searching for feasible ways to reduce the overall volume through physical simulations, and (3) demonstrating the steps to determine the optimal sizes and shapes of the components using a sample menu.

We have showed that two key factors must be considered: sequence of packing the components and the individual shape and size of each component for a given packing sequence and component locations. Testing the 8 different sample menu items, we demonstrated how such factors can be considered in designing both meal bag and tray. The practical sizes for the tray to accommodate all the menus are determined, together with the best sequences and locations of the components. We further tried to find an optimal sizes of the packet considering some possible best shapes of the components. The best answer we found generated about 15% reduction over the current meal bag in the total package volume.

In the following, we provide some recommendations in regard to the shapes and sizes of the LRP.

1. Individual specifications for the components

Through the study, we found that it would be beneficial to define separate specifications for each component. For example, Caramel Bar in the sample menu was using the largest possible size given in the military spec (7" length and 3 1/4 " width both inside for Candy Packet), while its net size is only 4 3/4" in length and 7/8" in width. A similar case was found for the entree packet. We noticed that such excess seal allowances require unnecessary volume in the meal bag/tray. As we showed in section 3.4 and table 3.2, if the military specifications are given more tightly and specifically for each component in every menu, it would be possible to obtain substantial savings in the total package volume. If the CRAMTD line uses trays on a form-fill-seal line equipped with some pick-and-place robot to fill the trays, careful re-evaluation of each component would be quite necessary. From our physical simulations, it is expected that using trays and a robot-aided line may cause substantial increase in the total package volume compared to the existing meal bag.

2. Vacuuming the tray

To further reduce the total volume of the packet, it may be useful to vacuum the meal tray. On the form-fill-seal line for CRAMTD, such vacuuming may be easily accommodated in the sealing station.

3. Reshaping the entree pouch

Considering the possible changes in the net shapes of the components, we note that the biggest component, entree pouch, is the best candidate to be considered for reducing the volume. A desirable shape of the entree is flat and rectangular, which may reduce the overall volume by allowing flatter meal bag/tray. A possible modification is as follows: Entree is packed into the mixing bag with the existing size of 5 1/2 X 3 1/2 X 8. It is flattened down to the height of 1 1/2 giving a rectangular shape in dimension of 6 1/2 X 3 3/4. The mixing bag then goes into the entree pouch. If a manufacturer uses a horizontal filling and sealing for packaging the mixing bag into the pouch, we expect that the flat rectangular shape would be maintained easily. The resulting sizes and shape of the pouch will be determined by the physical process to be used. However, we roughly estimate the resulting size of the pouch may be 7 1/2 X 5 (inside spec. for flat pouch).

Shapes of the other components would be affected by the entree pouch. We tested several hypothetical shapes, but it was hard to estimate or quantify the savings in the total volume. Main reason was that it was very difficult to have samples in the trial sizes. Also, it seemed that the savings would be marginal from the changes of the smaller components. As a result, we suggest more physical simulations and considerations regarding the shapes and sizes of the components and tray, once the physical layout and equipment are determined for the CRAMTD packaging line during the STP 9 Phase II.

We believe the suggested approach (define sequence and determine the best sizes) in this report can be effectively used for the Phase II study and implementation.

# References

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